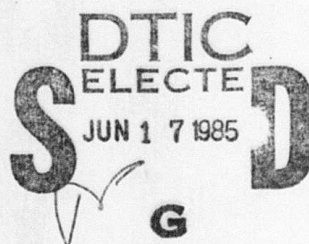# COMSAT Laboratories

QUARTERLY TECHNICAL REPORT

COMSAT PARTICIPATION IN DARPA PACKET SATELLITE INTERNETWORKING AND SPEECH APPLICATIONS PROGRAM

Sponsored by

DEFENSE ADVANCED RESEARCH PROJECTS AGENCY ARPA ORDER NO. A 0.3774

Monitored by

DEFENSE SUPPLY SERVICE WASHINGTON (DSSW) UNDER CONTRACT NO. MDA 903-79-C-0308
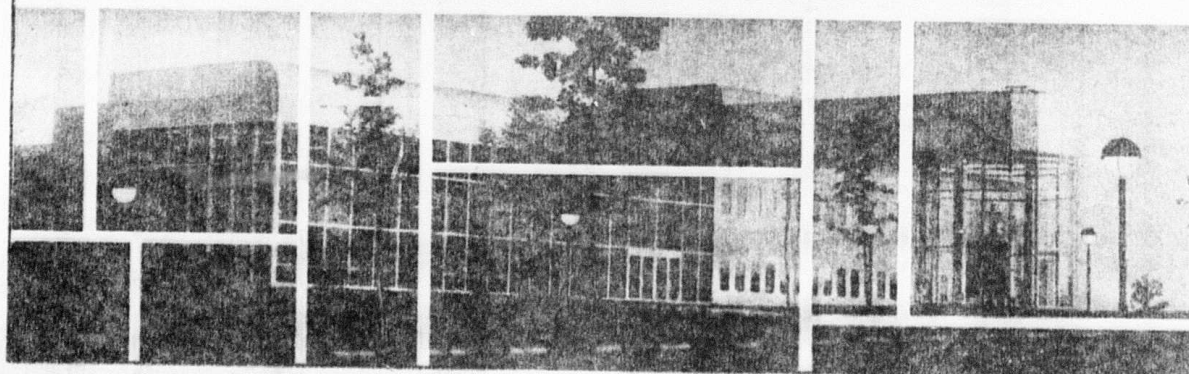
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January 1980

COMMUNICATIONS SATELLITE CORPORATION
COMSAT Laboratories, Clarksburg, Maryland 20734

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COMMUNICATIONS SATELLITE CORPORATION

950 L'Enfant Plaza, S.W.

Washington, D.C. 20024

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Second Quarterly Technical Report

15 June 1979 to 15 September 1979

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15 March 1979 to 15 June 1980

L. C. Palmer

Program Manager

301-428-4575

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ACKNOWLEDGEMENT

1. INTRODUCTION/SUMMARY

1.1   INTRODUCTION

This is the second Quarterly Technical Report issued under contract MDA 903-79-C-0308. This report covers COMSAT's activities from mid-June to mid-September 1979 under the three major task areas:

Task 1 - Transition of SATNET to Operational Status
Task 2 - Internetting Experiments
Task 3 - Wideband Integration/Coordination

of a contract under which COMSAT continues its participation in packet speech and internetting applications. Section 2 of this report review the work under Task 1 on SATNET's transition to operational status. Internetting activities are summarized in Section 3 and the technical work related to wideband system coordination is summarized in Section 4.

1.2   SUMMARY

Activities under Task 1 of this contract were re-stricted due to delays in completing delivery of the three Packet Satellite Program (PSP) terminals under a previous con-tract. The PSP terminal for Etam was delivered in late June 1979. The PSP terminal for the Goonhilly earth station was shipped at the end of August 1979 and initial installation was completed during the first week of September. Although the Etam PSP terminal operated in the network for a period of more than a month up through the end of August 1979, system problems arose at that time and the SPADE backup was restored.

A decision was made in mid-September to delay shipment of the third PSP terminal, which was scheduled for delivery to Tanum, Sweeden, until after the NTC demonstration in late November. Effort was therefore focused on resolving the SIMP/PSP incompatabilities in the terminals installed at Etam and Goonhilly.

The major effort under the contract during this reporting period was devoted to preparations for a live demonstration of the SATNET technology, which is scheduled for November 1979. This demonstration will be part of a session at the National Telecommunications Conference (NTC), which will be held in Washington, D.C. on 27-29 November. The demonstration will include packet speech and facsimile transmission between the conference site and University College London (UCL). COMSAT is presently coordinating the necessary hardware and software development between the major participants.

Activities under Task 3, wideband system coordination/ integration, have concentrated on additional computer simulations of candidate frequency plans for the EISN carrier. Meetings were held at Western Union in April, and again in July, to receive the most recent planning information for the EISN communication link. This information was incorporated into the simulation model and additional simulation experiments were performed.

2. ACTIVITIES UNDER TASK 1: TRANSITION OF SATNET
TO OPERATIONAL STATUS

2.1   INTRODUCTION

During the reporting period, two activities have been persued relative to the transition of SATNET to operational status. In July, the decision was made to request a nine month extension in the experimental status of SATNET. This status was due to expire in September 1979, but with a nine month extension, the experimental status would be extended until June 1980. The request for extension was submitted in August 1979.

A second activity under this task was continued monitoring of the SATNET data which is received each day from BB&N. A summary of these data for August and September is given in the remainder of this section.

2.2   SATNET PERFORMANCE DATA

Since January 1979, COMSAT has been compiling and summarizing the daily data on missed hello-packets in the SATNET system which is operating between Etam, Goonhilly, and Tanum. These data have provided useful information about the general quality of the nine SATNET links and their variability from day to day. It has also been possible to deduce link bit-error probability from the missed hello-packet data and to compare these results to the performance that would be expected in the SPADE transponder. The hello-packets are generated continuously

*Data prior to August is included in Section 6 of "Final Report, COMSAT Participation in ARPA Packet Satellite Program (PSP)," sponsored by DARPA, ARPA Order No. 3287, monitored by SAMSO/ YAPC under Contract No. F04701-C-0240, October 1979, by COMSAT Laboratories, Clarksburg, Md. 20734.

(approximately 66,000 per day) and are used only for synchronization. As such, the data on the success or failure of hello-packet reception gives useful, but indirect, evidence of the degree of success experienced by users who are transmitting message traffic via SATNET.

In April 1979, an additional summary of the SATNET channel data has been provided each day by BB&N. The new data applies directly to the efficiency of SATNET in handling the message traffic offered to it. The purpose of this subsection is to summarize the new data and to propose some overall "quality measures," for SATNET channel performance.

2.2.1   The SATNET Frame

The general format of the SATNET frame is shown in Figure 2-1. This frame structure has been in effect since April 1979. The data subframes are 27 virtual slots long. During a day there are 65,918 frames each of which contains 128 virtual slots. 84.4 percent of the virtual slots are available for sending message packets, and the rest are used for the hello-packets (3.1 percent) and the control packets (12.5 percent). With the total frame divided into four parts as shown in Figure 1, there are 4 x 65,918 = 263,672 PODA (priority-oriented demand assignment) frames in which data can be sent.

2.2.2   Proposed Measures for SATNET Performance

A simple model can be proposed to subdivide the total time in one day according to the following events:
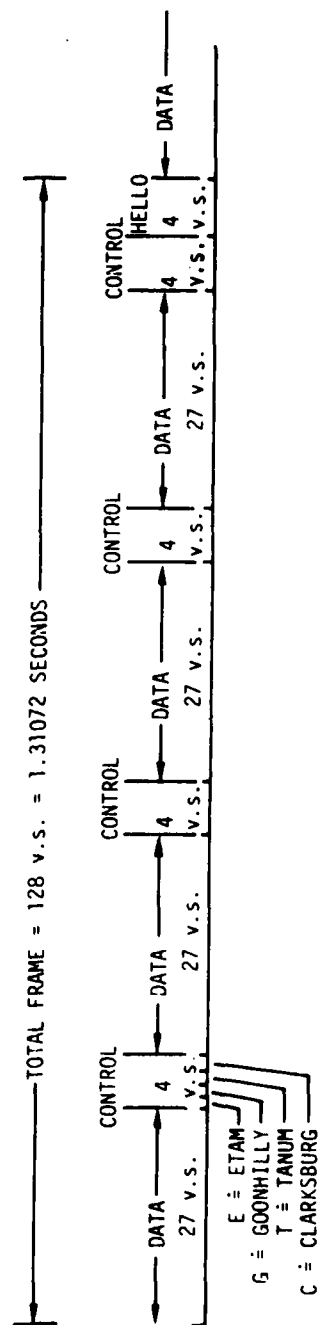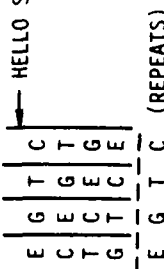
Figure 2-1. SATNET Frame as of April 1979

2-3

$O_1 \doteq$ the number of PODA Frames that are unavailable for transmission due to SIMP "outages." The SIMP outages fall into three categories; m_1 = minutes SIMP is cross patched, m_2 = minutes SIMP is in "loader/dumper," m_3 = minutes SIMP is not reporting. Using the conversion f $\doteq$ PODA Frames/minute = 263,672/1440 = 183.1, outage O_1 can be obtained as $O_1 = f(m_1 + m_2 + m_3)$ PODA Frames.

O_2 - The second form of outage occurs when the SIMP is operating and accepting traffic but the SATNET network is out of synchronization. These outages can be due to several causes i.e.,

    (a) hello frames out of sync,

    (b) SIMP is out of datagram reservation sync,

    (c) SIMP is attempting datagram initial acquisition, or

    (d) SIMP is out of stream sync

Note that O_2 should indicate the number of PODA frames that are unavailable for transmission due to synchronization problems. Presumably, the number of PODA frames in datagram reservation sync, which we can define as F_{in} can be obtained as

$$F_{in}(k) = 263,672 - O_1(k) - O_2(k) \qquad (2.1)$$

where;

    $F_{in}(k)$ - is the total number of PODA frames in datagram reservation sync at transmitting station k

    $O_1(k)$ - number of elapsed PODA frames during SIMP outages (available from the data) at station k

    $O_2(k)$ - number of PODA frames that transmitting station k is out of synchronization (likewise available from the summary data)

2-4

It is proposed that the first efficiency measure used is simply the ratio of $F_{in}/263,672$ denoting the "potential" PODA frames which are available for sending messages. That is,

$$\eta_1(k) \doteq \frac{F_{in}(k)}{263,672} = \text{"Availability"} \qquad (2.2)$$

This first efficiency measure asks the question, "is the system able to handle traffic if such traffic were presented to it?" The answer to this question can be "no" for two reasons; either the SIMP is down, or the station is out of synchronization. The measure $\eta_1(k)$ is an important first measure of "availability" and it seems to be readily available from the channel summary data.

A second important question is, how much traffic was the station called upon to transmit during the periods of time when it was "available" to transmit? This measures the loading presented to the earth station and this number also seems to be readily available from the data as the number of channel data packets transmitted, which will be denoted as $P_t(k)$. Unfortunately, the number of virtual slots consumed by each data packet are not known except that these are constrained as;

$$1 \leq \frac{\text{Virtual Slots}}{\text{data packet}} \leq 5$$

However, the average virtual slots per packet is not known. It is proposed for now that the loading is treated in terms of the parameter V_p, where V_p is assumed to be either 2 or 3 (See Table 2-1). Until more accurate information is available, a reasonable average for V_p will be assumed as 2.5; which will be denoted as $\bar{V}_p$.

Table 2-1. Assumed Format of Data Packets

Symbol Durations in Packet Excluding Data

Symbols Times for Carrier Acquisition	60
Symbol Times for Clock Recovery	60
Unique Word	16
Syn-Syn-DLE-STX Sequence	16
Header (17 16-bit words)	136
Data (variable)	
DLE-ETX Sequence	8
Check Sum	12
Total Length of packet excluding data and guard times	308 symbols = 9.63 ms

Guard Times

800 µ seconds for transmitter "overhang" time
335 µ seconds for guard time (due to timing inaccuracies)
240 µ seconds for the "staggering" of the packet-start
    times among the four earth stations

Total   1.375 ms

Data Bits in Packet (maximum)

#Virtual Slots Assigned to a User	Maximum Number* of Data Bits in Packet
1	0
2	592
3	1248
4	1904
5	2560

*Calculated for "N" virtual slots as [N x 10.24 ms - 9.63 ms - 1.375 ms] x 64 rounding to lowest number of 16 bit words.

Assuming an average packet length of $\bar{V}_p$ virtual slots, then the "loading" measure becomes

$$\eta_2(k) = \frac{P_t(k)}{F_{in}(k)} \frac{\left(\begin{array}{c}\text{Data packets}\\\text{Transmitted}\end{array}\right)}{\left(\begin{array}{c}\text{frames}\\\text{Avail}\end{array}\right) \cdot 27\left(\dfrac{\text{V.S.}}{\text{frame}}\right)} \cdot \bar{V}_p \dfrac{\text{V.S.}}{\text{packet}} \quad (\text{avg}) \doteq \text{"Loading"} \quad (2.3)$$

An additional measure of effectiveness is the ratio of total packets received at all stations to total packets transmitted. This ratio

$$\eta_3 = \frac{\displaystyle\sum_{k=1}^{3} P_r(k)}{\displaystyle\sum_{k=1}^{3} P_t(k)} \doteq \text{"Success"} \quad (2.4)$$

applies to the total network.[†]

A final measure that reflects total network loading is:

$$\eta_4 = \frac{\displaystyle\sum_{k=1}^{3} P_t(k) \cdot \bar{V}_p}{263,672 \times 27} \quad \begin{array}{l}\text{Virtual Slots}\\\text{used for Data}\\\hline\text{Total Virtual}\\\text{Slots/Day}\end{array} \doteq \text{Composite Loading}$$

The efficiency measures η_4 (Composite loading), η_3 (ratio total packets received to total transmitted), and $\eta_1(k)$ (availibility of station k; k = 1 for ETAM, = 2 for Goonhilly, = 3 for Tanum) are summarized in Table 2-2 for certain days in April 1979 when these data first became available.

[†]It has been found in reviewing subsequent summary data that the measure of success η_3 sometimes gives a number greater than one. When this number exceeds one, more packets are reported received than were reported as transmitted which simply means that some transmitted packets were not reported. The measure η_3 thus will not be very useful until the data reporting procedure is made more reliable.

Table 2-2. Channel Summary, April 1979

	20	21	22	23	24	25	26	27	28	29
PDSA FRAMES AVAILABLE										
E	227,385	249,769	252,388	253,363	199,611	242,151	226,010	40,414	250,143	
G	229,702	234,540	237,859	245,749	196,096	247,296	225,001	28,160	240,163	
T	137,070	246,840	251,880	256,146	200,192	238,592	202,282	28,138	218,208	
AVAILABILITY										
E	0.862	0.947	0.957	0.965	0.757	0.918	0.857	0.153	0.948	
G	0.871	0.890	0.902	0.936	0.744	0.938	0.853	0.107	0.911	
T	0.520	0.936	0.955	0.975	0.759	0.905	0.767	0.107	0.827	
DATA PACKETS TRANS										
E	233,246	60,391	159,046	370,815	180,813	277,236	147,136	32,174	273,084	
G	228,659	55,381	136,594	357,548	175,575	275,157	142,242	26,372	266,422	
T	6,144	13,759	11,792	13,714	8,416	9,060	9,184	2,952	12,354	
LOADING*										
E	0.076-0.114	0.018-0.027	0.047-0.070	0.108-0.163	0.067-0.100	0.085-0.127	0.05-0.072	0.06-0.098	0.08-0.12	
G	0.074-0.111	0.017-0.026	0.043-0.064	0.108-0.162	0.066-0.099	0.082-0.124	0.05-0.007	0.069-0.104	0.082-0.12	
T	0.003-0.005	0.004-0.006	0.003-0.005	0.0004-0.006	0.003-0.005	0.003-0.004	0.003-0.005	0.008-0.012	0.004-0.006	
COMPOSITE LOADING†	0.1643	0.0045	0.107	0.2805	0.128	0.1972	0.105	0.022	0.1938	
TOTAL NETWORK SUCCESS RATE	0.991	0.990	0.992	0.9995	0.9967	0.9981	0.9927	0.9927	0.9930	

*First entry assumes 2 v.s. per data packet, second entry assumes 3 v.s. per data packet
†Composite loading is based on an average of 2.5 v.s. per data packet, 263,672 x 27 virtual slots potentially available per day.

2.2.3   Conclusions

The objective here has been to propose some possible
ways to utilize the new channel summary data. These methods use
the data as it is presently available. Useful changes in format
or additional data would be:

a)   to measure and record average data packet length $\bar{V}_p$
      rather than having to guess that it is 2.5.

b)   to break out the data packet "success" percentages by
      link rather than having to deal with a composite
      overall "success" percentage. Actually, the composite
      number may be a useful summary as long as the data on
      missed hello packets is available. The latter gives
      a more detailed measure of success by link.

2.3   SUMMARY OF SATNET DATA; AUGUST, SEPTEMBER 1979

A compilation of the SATNET performance data for
August and September 1979 is given in Table 2-3 through 2-6.
Tables 2-3 and 2-4 give data on missed hello packets for the
two months. The monthly average miss percentage for all links
is 0.06 percent in August and 0.12 percent in September. The
trends of missed hello packets by day for selected links is given
in Figures 2-2 and 2-3 for August and September, respectively.

SATNET summary data for August and September is given
in Tables 2-5 and 2-6, respectively. As noted in Section 2.2.2,
the network success rate often gives a number greater than one
indicating more packets reported received than were _reported_
transmitted. This is a useful overall performance measure, but

Table 2-3. Hello Packet Data, August 1979

DAY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Avg.
Missed Hello Pkts.																																
Link 1	1	57	26	0	0	0	1	0	2	1	0	0	0	0	0	3	3	2	5	0	0	0	781		50	4		3	93	45	31	38
2	8	23	80	0	16	18	11	5	5	99	24	22	215	11	24	3	0	0	0	3	41	0	248		81	10		12	100	2	703	44
3	1	51	22	4	15	2	16	1	1	18	2	1	5	1	15	7	3	7	52	1	2	0	2056		0	3		0	12	1	74	74
4	2	6	0	1	2	1	2	1	4	0	0	1	3	1	0	0	0	0	0	34	1	0	0	114	20	2		70	138	298	66	
5	0	3	5	0	1	4	7	1	3	2	5	3	167	11	11	15	0	0	0	41	4	0	32		20	4		63	52	0	46	
6	0	168	3	60	14	3	20	2	4	14	4	3	9	6	6	1	0	0	0	37	2	0	0		0	12		16	87	1	112	
7	9	15	17	15	26	15	17	5	12	39	15	7	19	10	11	6	8	4	2	7	4	1	853		0	9		28	63	237	31	
8	7	15	44	21	23	23	24	10	17	43	15	10	76	22	21	10	8	4	0	44	13	0	0		0	10		28	86	0	91	
9	7	102	39	22	20	18	20	–	17	46	14	10	16	13	15	7	11	4	21	13	6	1	741		0	15		25	73	0	7	
Daily Avg.	4.1	47.3	26.2	13.7	10.7	9.3	13.1	3.1	6.9	29.1	8.8	6.3	56.7	9.3	11.4	5.8	2.8	1.9	8.9	20	8.1	1.2	523		29.4	7.7		32.0	78.2	64.9	76.1	59
Outage Corr. Fac.	1.17		1.46					1.44	1.34	1.41		1.13										2.72	1.60		1.46			1.14		1.46	1.35	
*																																
E	6	3	1	2	16	16	10	5	5	96	24	18	24	6	26	5	4	2	7	2	34	0	29		3	5		1	4	54	72	
G	0	0	0	0	1	1	4	0	2	0	2	3	6	1	2	4	0	0	0	3	0	0	0		1	1		1	1	2	2	
T	4	10	16	22	18	18	18	5	14	6	16	10	44	12	14	4	7	4	1	9	5	1	6		0	3		0	1	1	1	

*Hello packets received with hardware checksum errors

2-10

Table 2-4. Halo Rocket Data, September 1979

*Data problems associated with hardware shutdown affected

Table 2-5. SATNET Summary Data, August 1979

DAY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Monthly Average
% PDA Frames Avail. E	86.3	90.1	88.2	99.1	100	98.8	98.7	67.0		92.6	98.8	97.8	97.6	97.9	93.9	98.8	98.4	99.7	99.4	97.8	77.9	54.2	60.1		100	97.2	97.2	81.9	93.9	61.3	94.7	90
G	87.3	52.4	47.4	98.9	99.9	80.8	98.9	66.3		94.2	99.3	97.9	97.8	98.1	94.8	27.9	0	0	0	33.3	76.2	0	8.6		76.4	97.4	98.4	70.0	61.2	61.0	94.6	66
T	87.5	96.7	89.7	98.4	99.8	99.7	98.4	66.0		94.1	99.7	98.1	97.6	97.6	96.1	85.9	100	99.7	99.7	97.7	74.0	54.4	59.8		11.3	63.6	58.4	29.7	69.9	60.7	94.4	78
NPMt. Avg.	87.0	79.7	75.1	98.9	99.9	90.1	98.7	66.5		93.6	99.3	97.8	97.7	97.9	94.6	70.9	66.1	66.5	66.4	76.3	76.0	36.2	42.8		69.2	85.1	84.7	60.6	75.0	61.0	94.6	78
Conn. Pkt. Del. Rate (%) E	95	99	86	81	81	81	80	79		83	89	99	82	83	89	96	99	99	99	88	81	99	96		98	88	86	96	98	99	100	97
G	96	100	91	90	90	89	89	89		92	97	99	86	98	89	92	0	0	0	89	87	0	94		98	99	91	93	97	100	99	88
T	95	99	86	81	84	82	80	77		86	91	99	87	88	96	99	99	99	99	89	82	99	9?		94	88	85	95	98	100	99	88
NMdt. Avg.	95	99	87	86	85	84	83	82		87	90	99	85	87	91	96	66	66	66	89	83	66	96		97	87	87	95	98	100	99	96
Data Pkt. Del. Rate (%) E																																
G																																
T																																
NMdt. Avg.																																
Aug. 111 (%)	1.7	1.9	7.3	13.6	13.7	13.1	39.6	24.2		13.3	13.3	5.1	14.9	14.6	13.0	6.0	1.3	1.4	1.6	9.2	19.6	4.7	0.9		0.7	9.2	10.8	8.2	6.7	8.7	14.9	9.7

Table 2-6. SATNET Summary Data, September 1979

| DAY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Monthly Average
% PODA Frames Avail. E	99.5	89.3	99.7	99.4	97.4	94.2	86.0	99.1	99.8	93.0	93.0	94.6	92.0	80.7	95.4	94.2	96.9	97.8	95.8		61.1	91.0	23.2			80.9			74.7	50.4	87.1
G	99.2	89.1	99.0	95.8	95.2	36.6	61.4	73.6	80.0	91.4	91.4	95.8	90.1	82.3	96.0	93.9	97.3	97.2	94.9		38.9	89.8	23.3			81.5			42.5	74.7	80.4
T	99.4	89.1	99.7	68.2	71.8	85.1	84.7	99.3	99.7	92.1	92.1	92.2	92.5	82.4	96.6	93.6	95.9	91.7	95.8		16.6	27.6	23.4			53.4			81.0	95.0	80.8
Ndst. Avg.	99.4	89.2	99.5	87.8	88.2	72.0	77.4	90.7	93.2	92.2	92.1	94.2	91.6	82.0	96.0	93.9	96.7	95.5	96.5		38.8	69.4	23.3			71.9			66.1	73.7	82.8
Con. Pcht. Suc. Rate (%) E	100	100	100	77	93	99	94	94	94	96	96	94	92	93	93	100	97	92	93		95	94	84			87			91	93	94
G	86	100	100	83	96	99	90	91	91	95	95	94	92	93	92	99	95	92	91		95	94	88			94			89	92	93
T	100	100	100	45	86	99	93	92	94	91	91	92	93	92	92	100	96	93	93		91	85	82			84			90	91	91
Ndst. Avg.	95	100	100	68	91	99	92	92	93	94	94	93	92	93	92	100	96	92	92		94	91	85			88			90	92	93
Data Pcht. Suc. Rate (%)																															
Ndst. Avg.																															
App. Ndst. Load. (%)	15.0	12.7	13.2	22.2	13.7	7.8	7.3	11.0	12.7	26.3	26.3	41.5	28.0	13.2	20.5	16.1	32.6	25.6	20.3		0.5	2.1	4.7			18.9			1.0	5.9	16.0
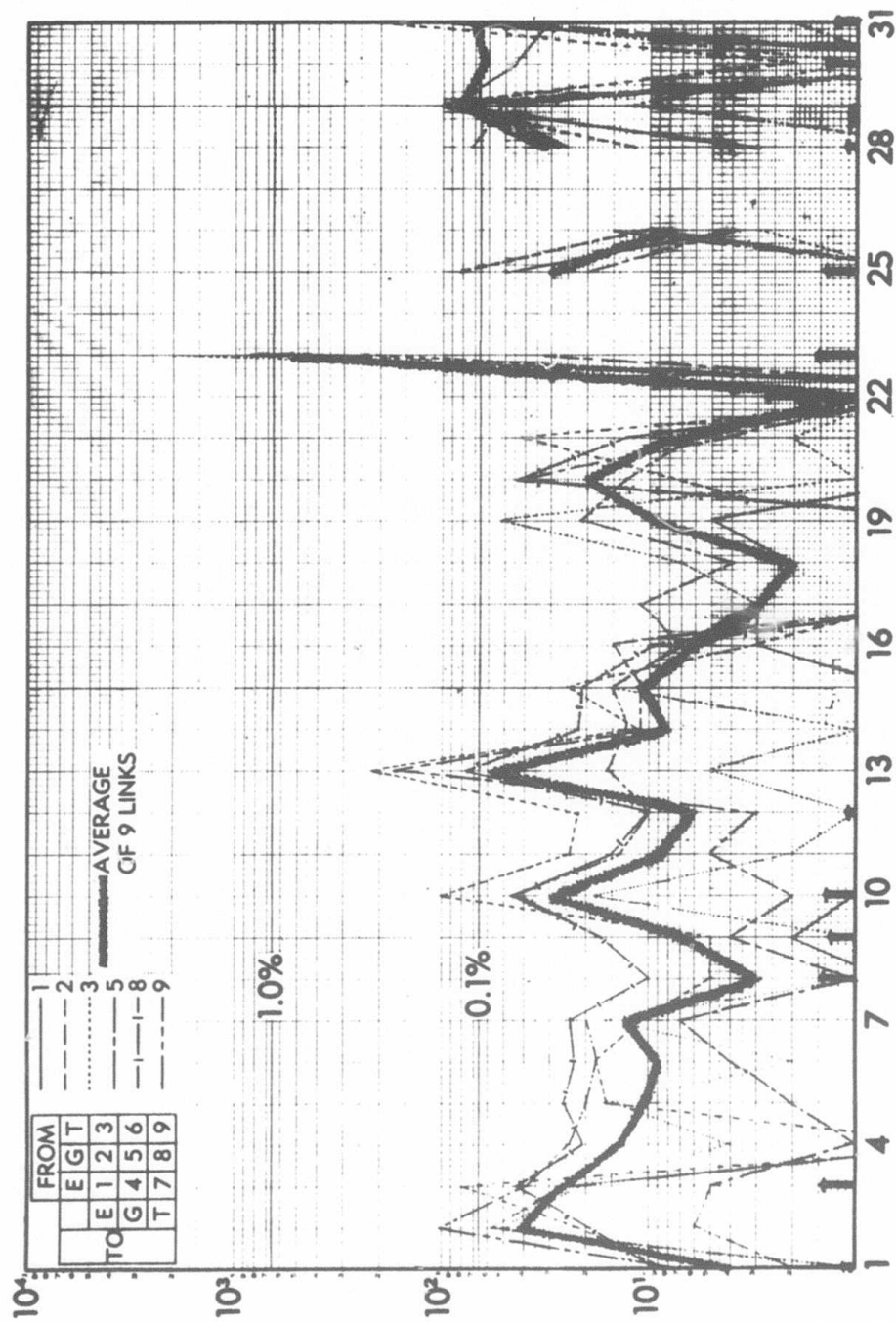
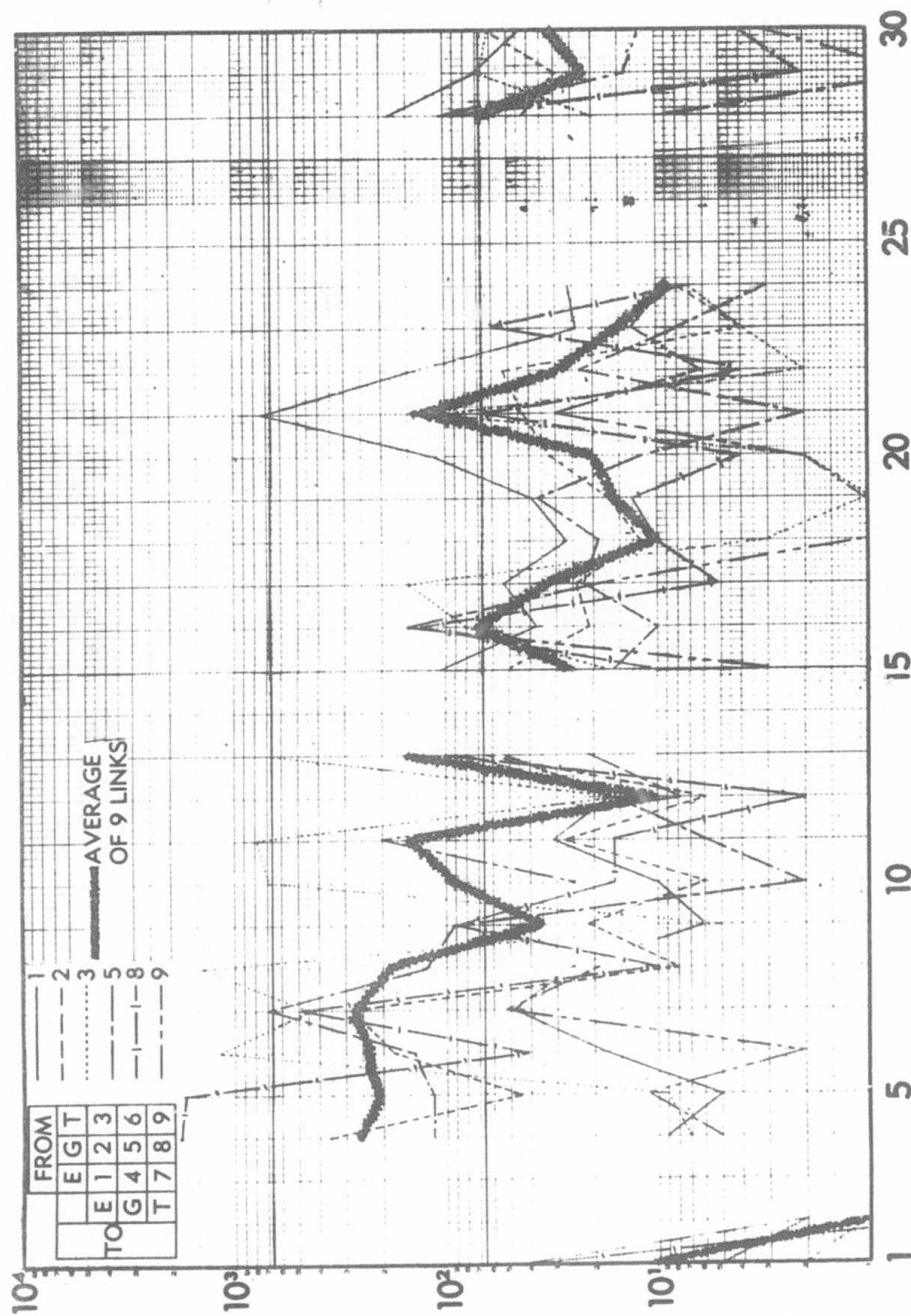Figure 2-2. Missed Hello Packets per day by Link, August 1979

Figure 2-3. Missed Hello Packets per day by Link, September 1979

it cannot be included in the performance summary until reporting
procedures are improved. These procedures as well as the processing
of the summary data is expected to evolve and be refined as SATNET
progresses toward applications support status.

3. ACTIVITIES UNDER TASK 2 - INTERNETTING EXPERIMENTS

3.1 PREPARATIONS FOR SATNET DEMONSTRATION

A major part of COMSAT's activities under Task 2 has
been the coordination of a demonstration of SATNET technology to
be held in conjunction with a technical session at NTC-79, to be
held in Washington in late November, 1979. The demonstration is
to highlight the multi-media and internetworking capabilities of
the system and is to involve packet speech, facsimile and record
traffic of various kinds. The vehicle for conducting this demon-
stration is to be a small computer system, called the Demo Terminal,
which includes interfaces for the Lincoln Laboratory LPCM vocoder
and Dacom 450 facsimile scanner/printer, together with a number
of peripheral devices. The software for this system, now under
development, is compatible with recent internet protocols developed
within the ARPANET community, including TCP-4, TELNET and special
protocols developed for real-time speech.

For the purposes of demonstrations and experiments, the
Demo Terminal is to be connected to a PDP 11 gateway computer now
located at COMSAT Laboratories in Clarksburg. This machine, which
functions as an interface to SATNET, is connected to the Clarks-
burg SIMP satellite channel interface computer in a manner similar
to other gateways, including those at BBN (Etam), NDRE (Tanum)
and UCL (Goonhilly). However, in the Clarksburg case the earth
station is capable of receiving only at a 16 kbit/s rate, rather
than the 64 kbit/s rate used by the other stations. This fact
considerably complicates the channel scheduling algorithm used to
determine which station transmits at a particular time, and the
software to support this mixed rate operation is not yet completely
developed.

From the standpoint of the November demonstration, it is highly desirable to demonstrate those aspects of the SATNET design which advance the state of the art vis-a-vis current systems. Probably the most important of these is the integration of real-time speech, which must be delivered subject to critical delay limitations, and record data, which can be delayed in the interest of efficient channel utilization. The equipment now in place at the various experiment sites provides the capability to support real-time speech and record data between domestic U.S. gateways and UCL (London) and between these sites and the U.S. and European ARPANET. It would be highly desirable to demonstrate facsimile transmission via SATNET, and work is now proceeding on implementing appropriate interface software. While it is probable that the demonstration could take place even without the facsimile capability, real-time speech is considered to be necessary for a meaningful demonstration and hence will be given priority.

An additional important goal for the demonstration is to be able to demonstrate full SATNET connectivity via the Clarksburg gateway and the UET; however, the present software can support this only in a marginal way. This is because of two factors. The first is that a special temporary connection has had to be made via SATNET to support older protocols until use of these protocols can be phased out. The second is that control information coordinating the channel scheduling process is now sent at the rate of the lowest-rate earth station in the net, 16 kbit/s when Clarksburg is active. Accordingly, at least for the demonstration, Clarksburg cannot be used on the operational SATNET channel, at least for speech.

To provide an effective demonstration including real-time speech, a connection to a gateway other than Clarksburg is required. This can be done in two ways, as shown in Figure 3-1. The only domestic U.S. earth station, other than Clarksburg, connected to
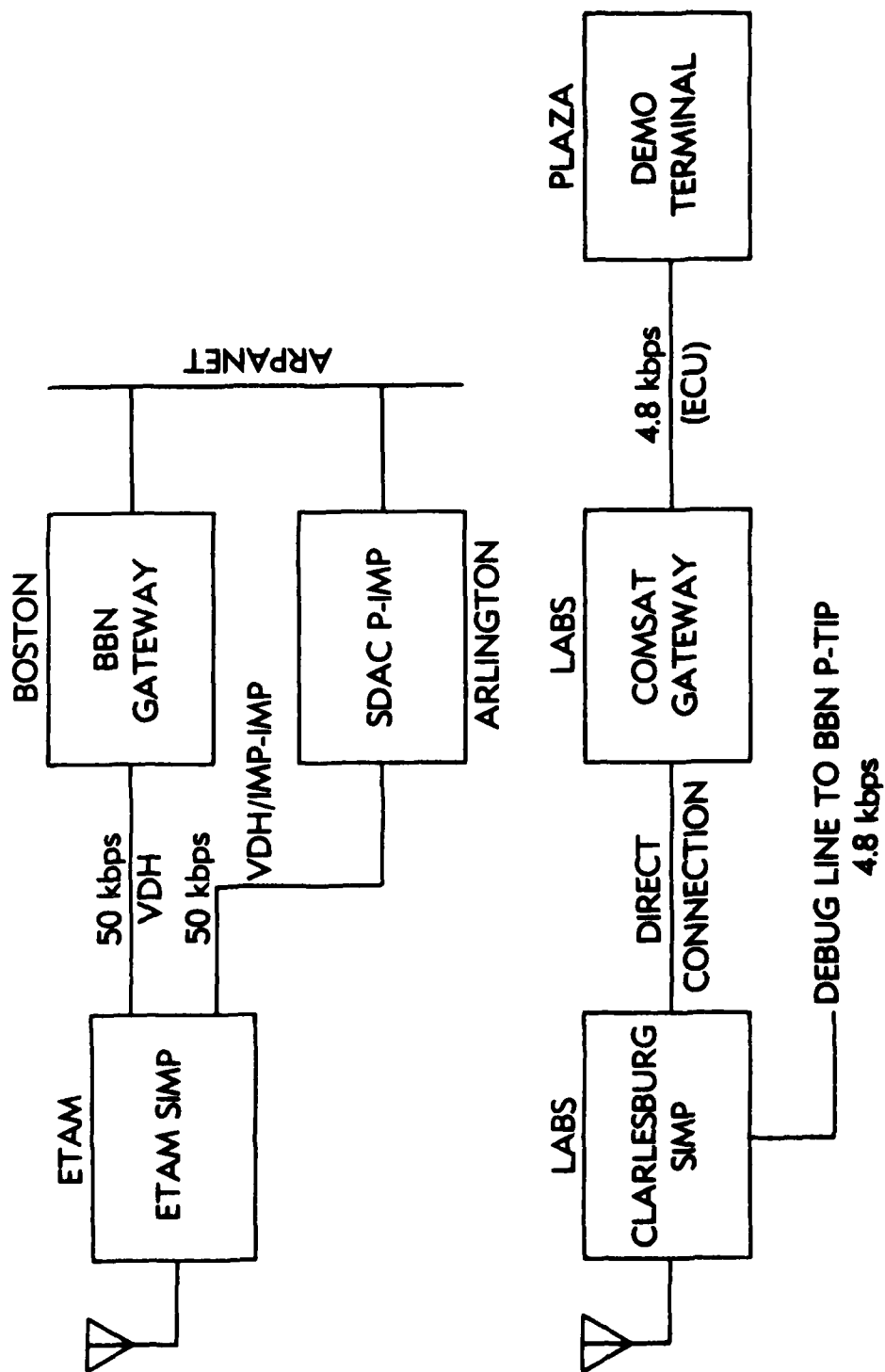
Figure 3-1. Possible Demonstration Configuration

SATNET is Etam. Normally it is connected via a line to the BBN
gateway in Boston and by another line to the SDAC Pluribus-IMP in
Arlington. The SDAC connection is operated on an IMP-IMP basis
in order to support the European direct-connection mentioned above
and on a Host-IMP (VDH) basis in order to perform certain tasks
related to maintenance and development. The BBN connection is
operated on a Host-IMP basis for SATNET traffic only. As a pos-
sible solution for Demo Terminal access to SATNET, a line could
be run from Clarksburg the COMSAT gateway to Etam and used instead
of the Etam-Boston line during the demonstration. The COMSAT
gateway would then temporarily replace the BBN gateway. Connec-
tivity via the Clarksburg SIMP could be restored by manually
switching or replugging the lines as required. However, recon-
figuration on-the-fly in this manner has previously been a source
of considerable trouble and, in any case, requires complex and
time-consuming software reconfiguration as well.

The second option, which is by far the most attractive,
is to run a line from the demonstration site to the BBN gateway.
This configuration, shown in Figure 3-2, provides full access to
SATNET via either Etam, Clarksburg or both. A problem with this
connection, however, is that connection to the domestic ARPANET
is possible only via a second satellite hop via Norway, which
introduces additional delay for this traffic. Nevertheless, this
connection provides the most reliable scenario, as well as allowing
direct comparisons between Etam and Clarksburg.

Although the Demo Terminal will support point-to-point speech,
it does not yet support conference speech, where several users
can share the common satellite channel in a controlled, dynamic
fashion. Software to support this mode has been implemented by
Lincoln Laboratories but runs only in the PDP 11 gateway machines.
The operational and logistic factors to support a demonstration
of conference speech would seem so extreme as to preclude its
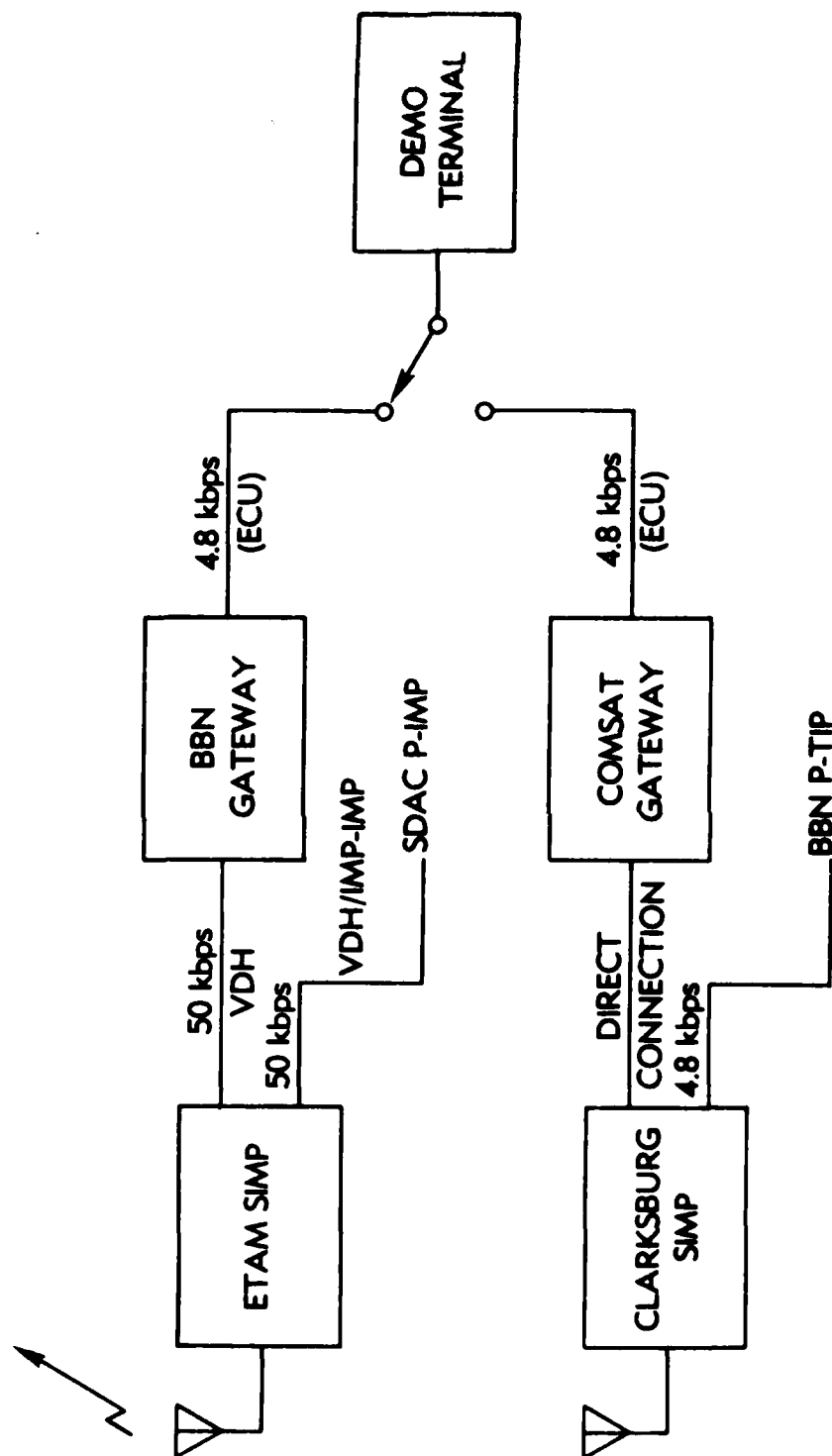
Figure 3-2. Alternative Configuration

possibility; however, a movie is now being prepared which shows a live conference in progress, and it may be almost as effective to show this instead.

There is an issue regarding connectivity between the Demo Terminal and gateways. With the present configuration, a pair of Error Control Units (ECU) are required for connection to each gateway. DARPA has agreed to provide a pair of these for connection between the COMSAT gateway and Demo Terminal; however, a second pair will be required for connection to the BBN gateway. Since the latter pair will be necessary only for a short time bracketing the demonstration, efforts will be made to borrow these units from another site.

In summary, the following seems an appropriate plan to implement the November demonstration:

a. Order a 4.8 kbit/s digital line from the convention site to Clarksburg and Boston. These would be installed approximately a month before the demonstration and removed shortly after.

b. Borrow an additional pair of ECU's from elsewhere in the ARPANET community for about a month, coinciding with the above.

c. Lease a Dacom 450 facsimile terminal for a period of about three months. This would allow time to develop the hardware and software interfaces between it and the Demo Terminal and, finally, to demonstrate the capability for transmission between it and UCL (which also has compatible equipment and can run the same software) and for archiving, etc., with ARPANET hosts.

d. Plan on moving the Demo Terminal and the Dacom 450 to the convention site a few days before the demonstration for last minute checkout.

The overall configuration planned for the November demonstration is shown in Figure 3-3.

Figure 3-3. Network Configuration for Demonstration

3.2   INTERNETTING ISSUES

3.2.1   USE OF TCP AND RTP IN THE DEMO TERMINAL

Several issues are explored concerning operation of
internet protocol modules in the Demo Terminal which runs DCN
software. These protocol modules are designed to support inter-
net connections with hosts on other networks, including SATNET,
PRNET and ARPANET for real-time (speech) and record traffic.

The DCN supports user processes which can run the RT-11
system and user programs. Insofar as practical, the internet
interfaces to these processes have been cast in a manner com-
patible with the RT-11 programming conventions, so that appli-
cation programs can be constructed in high-level languages such
as FORTRAN. The implementation described here supports multiple-
connection user and server access to TCP, as well as raw internet
datagram access for real-time speech.

3.2.2   ARCHITECTURE OVERVIEW

The basis for much of the implementation is the TCP4
and TELNET modules for SRI. These have been modified for use in
the Basic Operating System (BOS), which supports the DCN in LSI-11
machines. In general, the modifications required have been minor
and preserve the general philosophy and integrity of the original
design. The general organization, shown in Figure 3-4, includes
a single process as the internet attachment for a number of con-
nections, all of which must be in the same machine (called a hostel)
as this process. A gateway process, which can be in a different
hostel, interfaces the internet process to the outside world (that
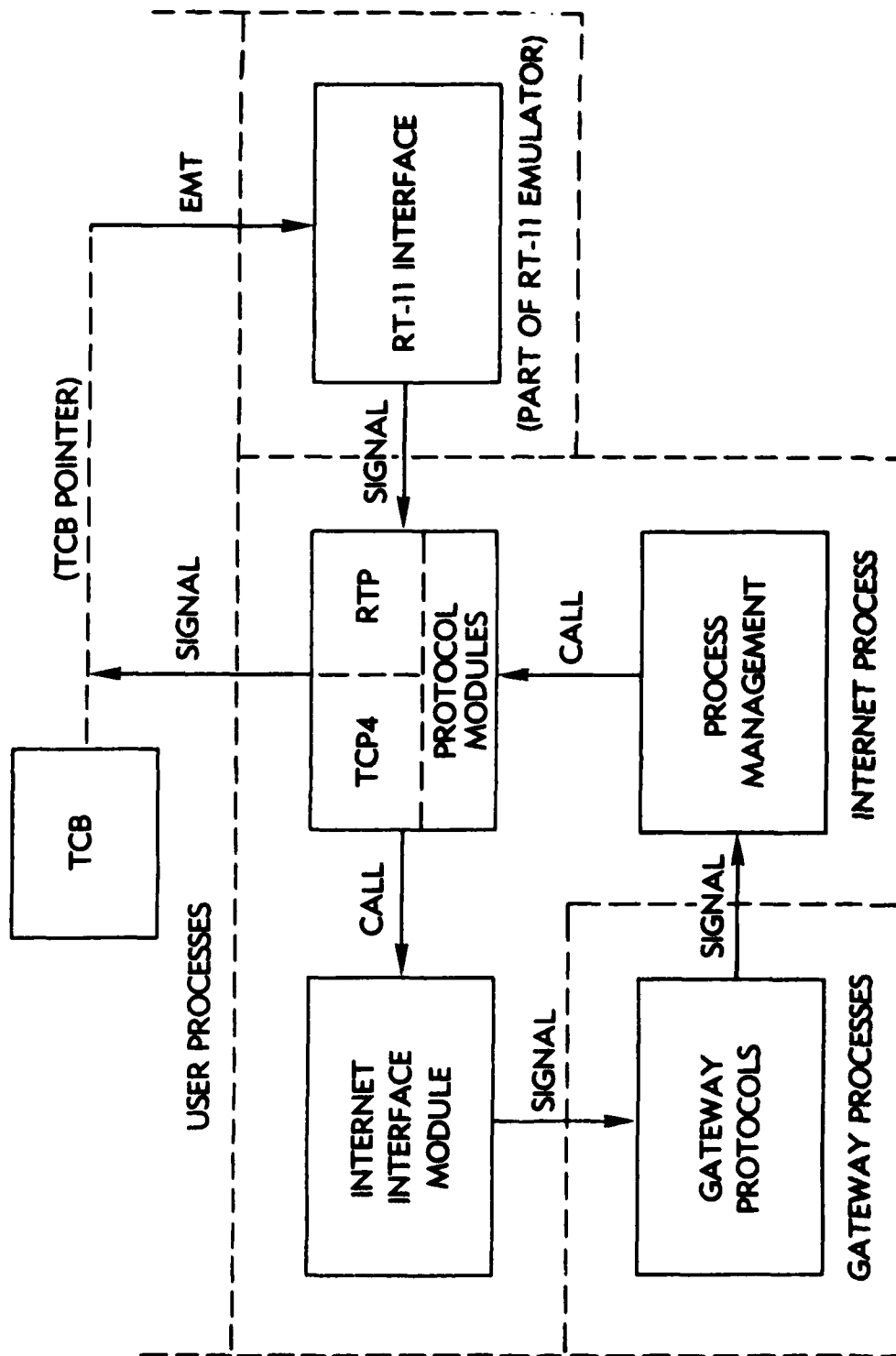is, outside the collection of hostels which represent the DCN)

Figure 3-4. System Architecture

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via a network-specific driver. In the COMSAT case this driver connects to the COMSAT gateway via an 1822 link and is compatible with the Port Expanders.

Interface to user processes is via a set of routines which operate as part of the RT-11 emulator package for the BOS. A number of programmed requests (EMT's) are provided to perform the TCP4 functions of $OPEN, $CLOSE, $SEND, $RECV and $INT (the last is not implemented yet).

The internet process, user processes and gateway process communicate with each other using short messages similar in function to the $SGNLI primitives of MOS. Where necessary, these point to packet buffers allocated from a common pool shared by all processes in the hostel.

In the original TCP4 design the network drivers were closely coupled to the TCP process itself. In the DCN design the gateway process (and possibly the user process) may be required to reside in different hostels. For this reason the TCP4 packet-allocation strategy was changed so that packets are always allocated by the process that fills them and deallocated by the process that empties them. In the case of packets exchanged between hostels, for example, the gateway process allocates a packet buffer for a packet received from the COMSAT gateway and passes it to the internal device driver for transmission to the hostel containing the internet process. Once transmitted (and ACKed if required) the packet buffer is de-allocated. The internal device driver in the internet hostel allocates its own packet buffer and passes it to the internet process, which consumes its contents and then deallocates it. Flow control is maintained by end-to-end acknowledgements (in this case from the internet process to the gateway process via the internal drivers) which take a form similar to the $SGNLI messages mentioned above. These mechanisms require no packet buffers and are buffered separately.

3.2.3   INTEK T CONNECTIONS

Each internet connection supported by a single internet process is described by a control block called the TCB. At present there are two protocol modules that can run in such a process -- TCP4 and RTP. The choice of which of these modules to use for a particular connection is determined by a protocol field in the TCB and by the protocol field in the internet header. The user interface to each of these is the same, with the exception that the full complement of connection-related signals (open/close complete, etc.) is available only with TCP. Date exchanged via TCP is, of course, guaranteed reliable and in sequence, while date exchanged via RTP consist of raw internet datagram packets. Present plans call for implementation of certain internet options necessary for SATNET stream access only in RTP, although they may be incorporated into TCP in the future.

The present design can support a number of internet processes and protocol modules in the same or different hostels, but it is not necessary that each hostel has every module. In these cases data are exchanged using the existing DCN protocols, which assume reliable, sequenced delivery using the same message system used to transport packets and $SGNLI messages. A practical scenario might include an internet process and RTP protocol module in one hostel, a speech module in another and a control program in a third, with operator terminal and gateway access in any of these or in a separate hostel. Present plans call for all of these functions in a single 30K-word hostel which provides, for example, about 8K words for a speech application program and 4K words for a TELNET user/server.

A particularly crucial issue is where to put the largish TCB, currently about 2000 (decimal) words. In a multiple-connection application such as FTP these TCB's, together with packet buffers,

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can consume a large fraction of the available hostel storage. A
frequent problem with MOS and ELF implementations has been exhaustion
of what can loosely be called supervisor storage, or storage that
is not mapped in the virtual sense. In the BOS implementation
TCB's are in user space, so that potentially a moderately large
number of connections can be sustained without straining supervisor
storage, which is then available for packet buffers and other
storage structures required to be "wired down" for DMA data transfers.
This philosophy requires the internet protocol modules to perform
a virtual-windowing operation to map the TCB into the address space
of the supporting internet process. In the structure shown in
Figure 3-4 the internet protocol modules are implemented as sub-
routines using register R5 as a base register. It is a simple
matter to extend this base by means of a reserved segment in the
kernel-space memory-management hardware, so long as the TCB itself
is wired down and not swapped to secondary storage. Extensions
to the implementation to provide these features would be simple
and possible with PDP11/40 or LSI-11/23 hardware.

3.2.4   MULTIPLEXING BEYOND THE TCP/RTP

        The internet address uniquely specifies an internet
process in the DCN, while the protocol field specifies whether
TCP4 or RTP protocol module is selected. It is natural and inviting
to interpret the 16-bit port field in the internet header as the
DCN port address of the user process. Unfortunately, such an inter-
pretation does not provide for multiple connections to a single
process and does not match with the interpretation used by the
Terminal Interface Unit (TIU) software. In the present implementa-
tion the port field is left uninterpreted and is established by
the user process in an $OPEN operation. An incoming message re-
ceived by the internet process is associated with the proper

connection by simply searching and matching the corresponding port
fields in the message and the TCB. The only requirement is that
this association is unambiguous.

In the TIU software the internet address itself is used
to provide this multiplexing function, since the port field is
conventionally used within the ARPANET to establish the type of
server (TELNET, FTP, etc.) requested. This hack would cause much
grief in the DCN and is replaced by the mechanism described above.
Further discussion is advisable on this point.

By convention, port 23 on the TCP for every internet
process is reserved for an RT-11 server process compatible with
TELNET. The TCB for this server is allocated "out of band" in an
area normally used by device drivers in RT-11. Additional TCB's
for other connections can be allocated elsewhere in this and other
user processes. Also by convention, port 1 is reserved for a
TELNET user process, which runs SRI TELNET virtually unchanged.
Internet echo and sink processes are included in the system for
testing. Internet datagrams from TCP or RTP are simply returned
to the sender with local and foreign address fields interchanged.

3.2.5   OTHER ISSUES

At present there is no support for the urgent or interrupt
mechanism in either TCP or TELNET. Facilities already exist in
DCN to propagate these functions beyond the TCP, and they will be
required in any real application. TELNET itself is largely super-
fluous in the system and its functions can be provided by using
existing DCN mechanisms augmented by suitable TELNET option-
negotiation mechanisms.

A provision for file transfer between DCN hosts separated
by SATNET is urgently needed, as well as a provision for file

transfer between these hosts and an ARPANET host. Using the
facilities currently implemented (namely multi-connection TELNET)
it is possible to implement a minimal version of ARPANET FTP. A
workable, if unatractive, interim file-transfer mechanism might
be to use the present DCN file-transfer package, designed to work
through a TIP, on a TELNET connection to an ARPANET host.

4. ACTIVITIES UNDER TASK 3: WIDEBAND INTEGRATION/COORDINATION

4.1   INTRODUCTION

COMSAT's participation in the wideband domestic network planning (also referred to as EISN, for Experimental Integrated Switched Network) has concentrated on a review of communications link performance predictions and simulations of several candidate frequency plans. Information collection began in April of this year when the implementing organizations (Western Union and Linkabit) provided information relative to communication link characteristics and modem design parameters. This information was incorporated into a simulation of overall link performance. This detailed information was summarized in the First Quarterly Report.

In this report, EISN link budgets are reviewed in the next subsection. Simulation results are presented in the next two subsections for candidate frequency plans that are the most likely final configurations of the WESTAR transponder that will contain the EISN QPSK carrier.

4.2   REVIEW OF LINK BUDGETS

The link budgets for the up-link of the wideband channel are summarized in Table 4-1. Up-link C/N is obtained as:

$$(C/N)_{up} = \psi_{sat} \cdot bo_i \frac{G\lambda_u^2}{4\pi} M_u/(kT_sB_a)$$

Table 4-1 Up-link Characteristics for Transmission
of QPSK Carrier

Earth Station	Reston	Lexington	Menlo-Park	Marina Del-Ry	Remarks
Up-link Saturation Flux Density ψ_s (dBW/m^2)	- 82.0	- 82.8	- 82.3	- 81.2	
Satellite TWTA Input Backoff (dB)	- 21.0	- 21.0	- 21.0	- 21.0	QPSK-carrier
$\lambda_0^2/4\pi$ (dB)	- 37.1	- 37.1	- 37.1	- 37.1	Assumes frequency
Satellite G/T$_s$ (dB/°K)	- 6.8	- 6.0	- 6.5	- 7.6	
Rain Attenuation Margin (dB)	- 0.5	- 0.5	- 0.5	- 0.5	
Bandwidth (dB-Hz)	- 63.0	- 63.0	- 63.0	- 63.0	B$_a$ = 2 MHz
k (dBW/Hz/K)	+228.6	+228.6	+228.6	+228.6	
(C/N)$_{up}$ (dB)	+ 18.2	+ 18.2	+ 18.2	+ 18.2	

4-2

where

$(C/N)_{up}$ = is the up-link C/N ratio in the allocated spacecraft bandwidth

ψ_s = spacecraft saturation flux density

bo_i = input backoff to the transponder

G = satellite receive antenna gain

λ_u = operating wavelength on up-link

M_u = up-link rain attenuation margin

k = Boltzmann's constant

T_s = satellite receive noise temperature

B_a = allocated bandwidth.

The HPA requirement (P_{HPA}) to produce the correct carrier level at the satellite can be obtained from:

$$\frac{P_{HPA} \cdot G_{ES} L_T}{4\pi R^2} = \psi_s bo_i \qquad (4.2)$$

where

P_{HPA} = required power from HPA

G_{ES} = earth station antenna gain

L_T = line loss HPA to antenna

R = distance from earth station to satellite.

The required earth station HPA capability is tabulated in Table 4-2.

The down-link C/N levels can be obtained from the relationship

$$(C/N)_{DN} = \frac{e.i.r.p._s \; bo_o}{4\pi R^2} \; M_D \; \frac{\lambda_D^2 \; G_{ES}}{4\pi} \; \frac{1}{kT_{ES}B_a} \qquad (4.3)$$

Table 4-2. Required HPA Capability

	Reston	Lexington	Menlo Park	Marina Del-Rey	Remarks
Saturation Flux Density ψ_s (dBW/m^2)	-82.0	-82.8	-82.3	-81.2	
Satellite TWTA Input Backoff (dB)	-21.0	-21.0	-21.0	-21.0	
Beam Spreading Loss ($4\pi R^2$) (dB)	162.5	162.7	162.5	162.4	
Transmit Antenna Gain (dB)	-47.9	-47.9	-47.9	-47.9	
Line Loss (dB)	0.9	0.9	0.9	0.9	From HPA to antenna feeds
Power required from HPA (dBW)	+12.5	11.9	12.2	13.2	
Maximum HPA power available	18.75	18.75	18.75	18.75	75 W tube
Margin for HPA backoff, clear sky (dB)	6.3	6.9	6.6	5.6	

where the terms not previously defined are

e.i.r.p._s = saturated e.i.r.p. of satellite

bo_o = output backoff of QPSK carrier

M_D = down-link loss due to rain

λ_o = down-link operating wavelength

G_{ES} = gain of earth station

T_{ES} = effective noise temperature of earth station

The down-link relationships are tabulated in Table 4-3.

Table 4-3. Down-Link Relationships
and Overall Performance

	Reston	Lexington	Menlo Park	Marina Del-Rey	Remarks
e.i.r.p. at saturation (dBW)	35.0	33.9	34.3	33.9	QPSK-carrier
Output backoff (dB)	-16.0	-16.0	-16.0	-16.0	
Path-Loss (dB)	-195.7	-195.8	-195.7	-195.7	
Rain Margin (dB)	-0.1	-0.1	-0.1	-0.1	
G/T (dB/K)	22.0	22.0	22.0	22.0	
Bandwidth (dB-Hz)	-63.0	-63.0	-63.0	-63.0	$B_a = 2$ MHz
k(dBW/Hz/K)	228.6	228.6	228.6	228.6	
$(C/N)_{DN}$ (dB)	10.8	9.6	10.1	9.7	
$(C/N)_{UP}$ (dB)	18.2	18.2	18.2	18.2	From Table 4-1
Total Interference Allocation C/I (dB)	19.0	19.0	19.0	19.0	(Assumption)
Total Available Overall $(C/N)_T$	9.6	8.6	9.0	8.7	C/N in 2 MHz BW
Overall Available C/N_o (dB-Hz)	72.6	71.6	72.0	7..7	
E_b/N_o Required for 5×10^{-3} Raw Channel Error Rate (dB)	5.3	5.3	5.3	5.3	Theoretical
Modem Implementation Loss (dB)	1.5	1.5	1.5	1.5	Assumed
Conversion from E_b/N_o to E_s/N_o (dB)	3.0	3.0	3.0	3.0	$E_s/N_o = \dfrac{\text{Energy per QPSK Symbol}}{\text{Noise Density}}$
Bandwidth Correction $(1.544 \times 10^6 / 2 \times 10^6)$(dB)	-1.1	-1.1	-1.1	-1.1	C/N above computed in 2 MHz Bandwidth
Required "C/N" in 2 MHz Bandwidth (dB)	8.7	8.7	8.7	8.7	
Marginal Overall (dB)	+0.9	-0.1	+0.3	0	Comparing $(C/N)_T$ available to Required

In the lower part of the table, overall C/N is obtained, $(C/N)_T$. This value is compared to the C/N required to guarantee a "raw" channel error rate of 5×10^{-3}. This raw channel error rate would, of course, be improved by any error control coding used on portions of the transmitted packets. These results apply to QPSK transmission at a symbol rate of 1.544×10^6 symbols/second and an information bit rate of 3.088 Mbit/s.

4.3 EVALUATION OF CANDIDATE FREQUENCY PLANS

4.3.1 INTRODUCTION

Several candidate frequency plans have been evaluated by computer simulation to determine overall losses to be expected for the 1.544 M symbol/second EISN carrier. These plans were re-covered from Western Union at two different meetings. The cases examined can be summarized as follows:

a. At a meeting held with Western Union (McLean, Virginia) on 27 April 1979, a frequency plan was obtained where the EISN carrier would share the WESTAR transponder with a single 660-channel FDM/FM carrier.

b. On 9 July, another meeting was held at Western Union (Upper Saddle River, New Jersey) where three additional candidate frequency plans were obtained. One of these involved the exclusive use of the transponder by the EISN carrier. The second, referred to as the "hybrid transponder" plan, was the most likely final configuration, and emphasis was focused on investigating this plan. A third possible plan called for the EISN carrier to share a trans-ponder with six T-1 carriers. To date, this third additional plan has not been simulated.

Preliminary simulation results for the two plans simulated to date
are given in the next two sections. The detailed simulation model
and most of the element characteristics were described in the First
Quarterly Progress Report.*

4.3.2   SIMULATION RESULTS FOR ORIGINAL TWO CARRIER FREQUENCY
          PLAN

          The examination of the original EISN frequency plan
addresses the case where the EISN carrier shares the transponder
with one other relatively wideband FM carrier.

          For the computer simulations, the 36 MHz transponder is
assumed to be accessed by the 1.544 M symbol/second QPSK ARPA carrier
and by a 660-channel FDM/FM carrier. The general frequency plan
is shown in Figure 4-1. Baseline modem back-to-back simulations
were made giving the eye diagram and scatter diagram shown in
Figure 4-2a and b, respectively. Simulated modem performance with
ideal synchronization is shown in Figure 4-3.

          From the simulation results, the maximum (worst case)
out-of-band emission levels can be predicted using the simulated
spectra in Figure 4-4. This spectral density applies to the case
where the earth station HPA is operated with no output backoff.
An estimate of the reduction in out-of-band emission levels, as
the earth station HPA is backed off, is given in Figure 4-5. Note,
for example, that operation with 6 to 7 dB output backoff (see
Table 4-2) would reduce the out-of-band emission levels by approx-
imately 5 dB.

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*"First Quarterly Progress Report," under Contract MDA-903-79-C-0308,
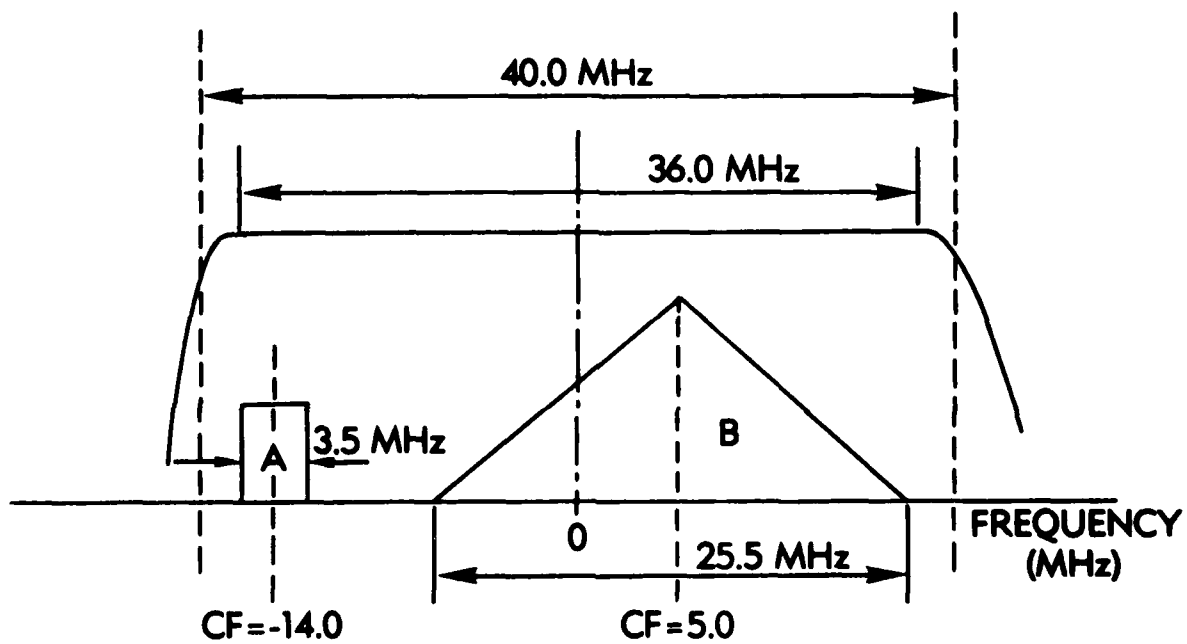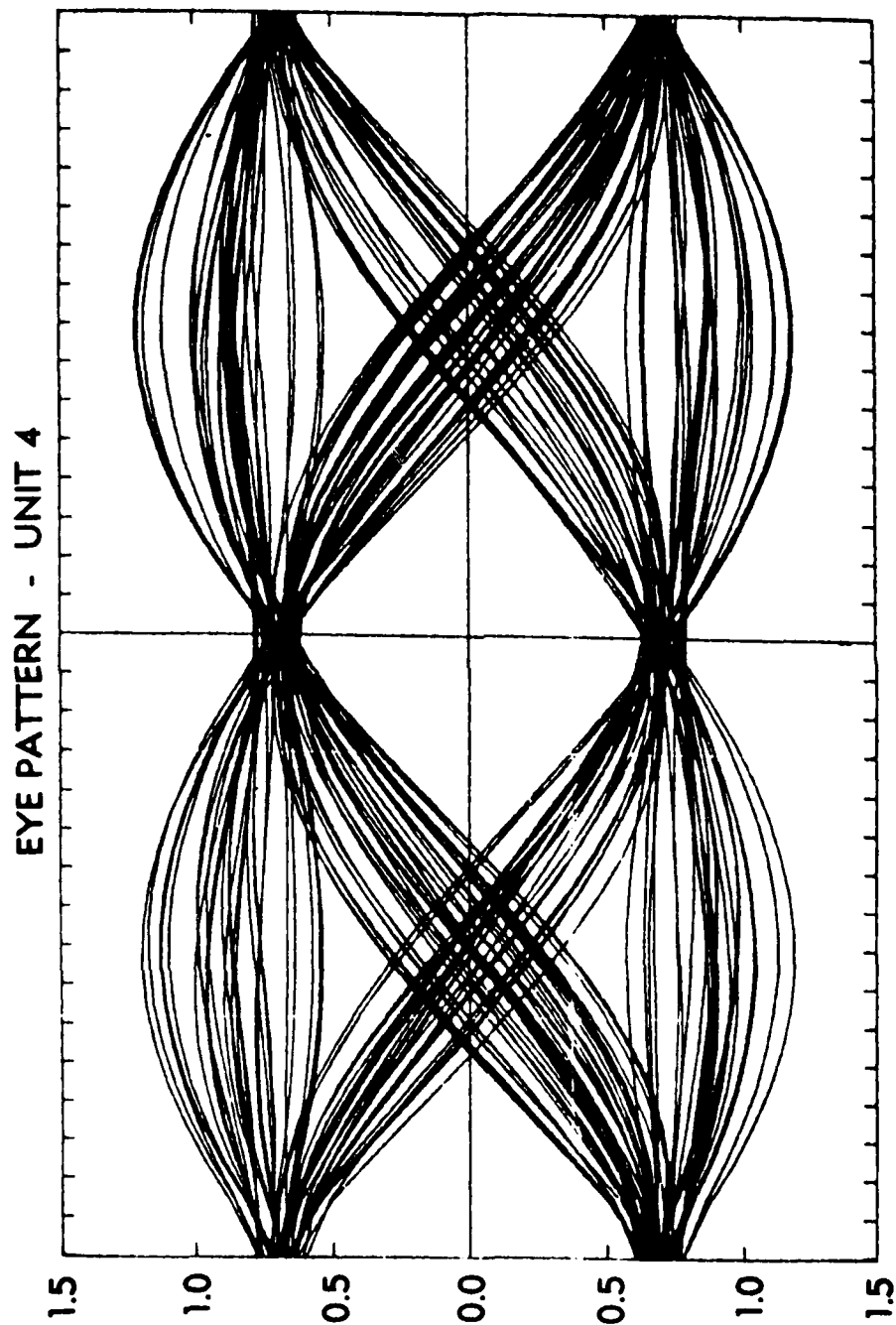 by COMSAT Labs, dated December 1979.

Figure 4-1. Original Frequency Plan for the Westar Satellite
Transponder Carrying the 1.544 Mbaud QPSK ARPA Carrier

EYE PATTERN - UNIT 4

BAUD RATE = 1.544
SAMPLE RATE = 24.704

TO, PHZO = 24.54, -0.00

Figure 4-2a.   Modem Back-to-Back - Eye Diagram

SCATTER DIAGRAM - UNIT 5

PHASE OFFSET (DEG) = 0.0
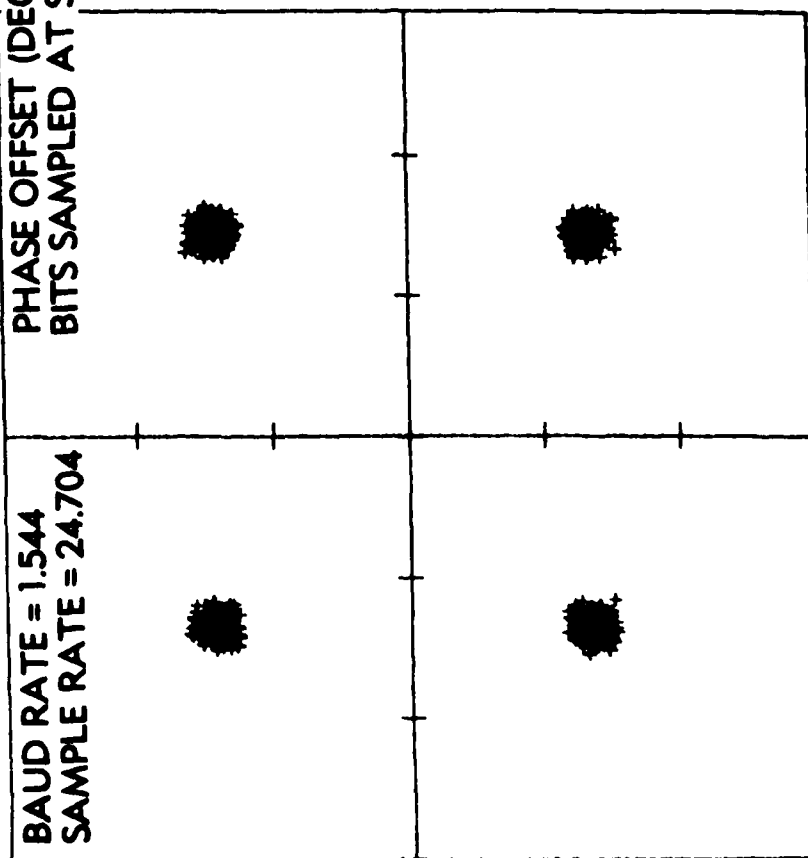BITS SAMPLED AT SAMP. NO. 8.50 (8.54)

BAUD RATE = 1.544
SAMPLE RATE = 24.704

Figure 4-2b.   Modem Back-to-Back - Scatter Diagram
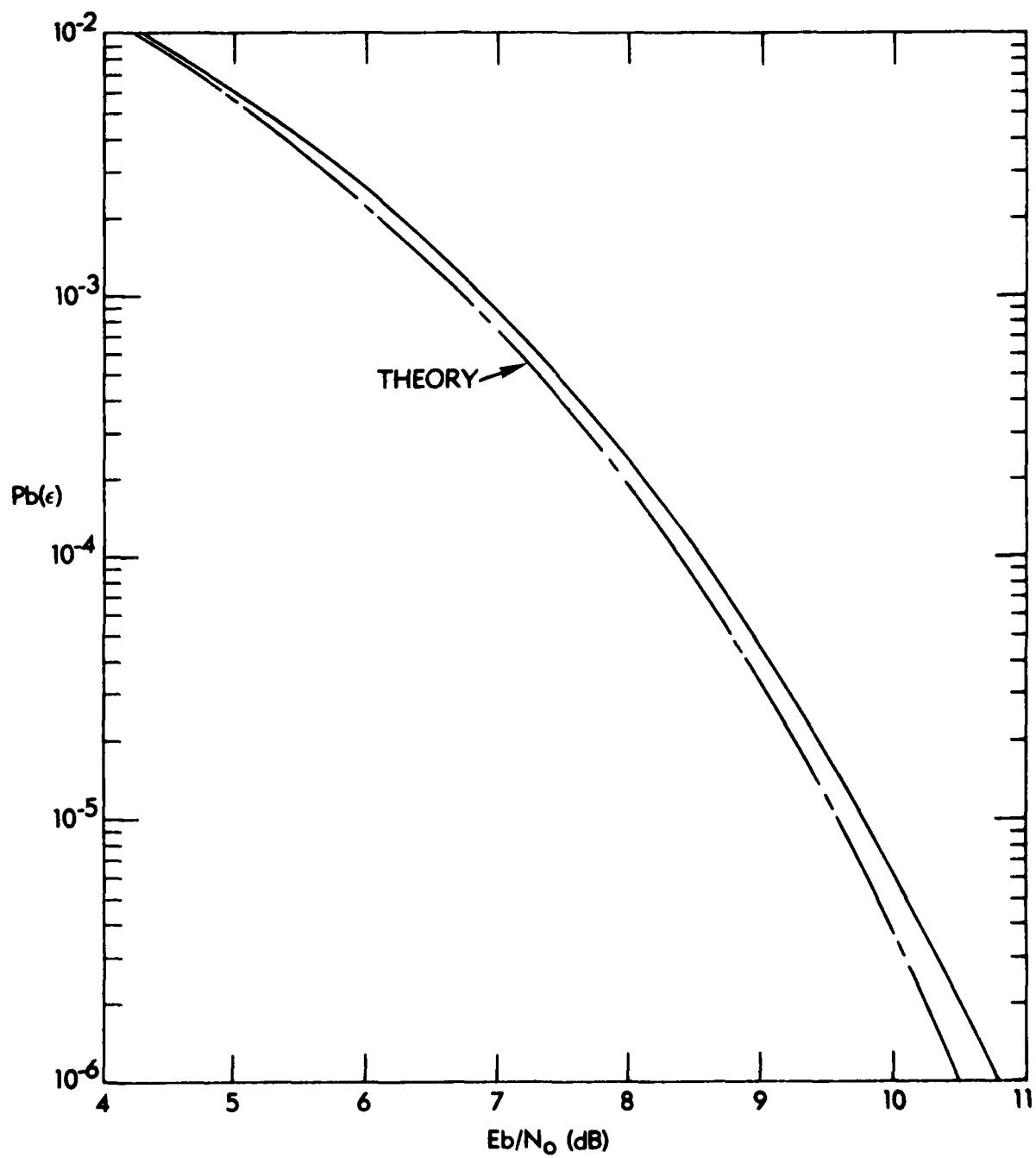
Figure 4-3. Back-to-Back Performance - No Synchronization
Errors

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ABSOLUTE POWER (DB)   NO WINDOW UNIT-4

34.1 dBW/4 KHz
(e.i.r.p.   60.0 dBW)

18.1 dBW/4 KHz
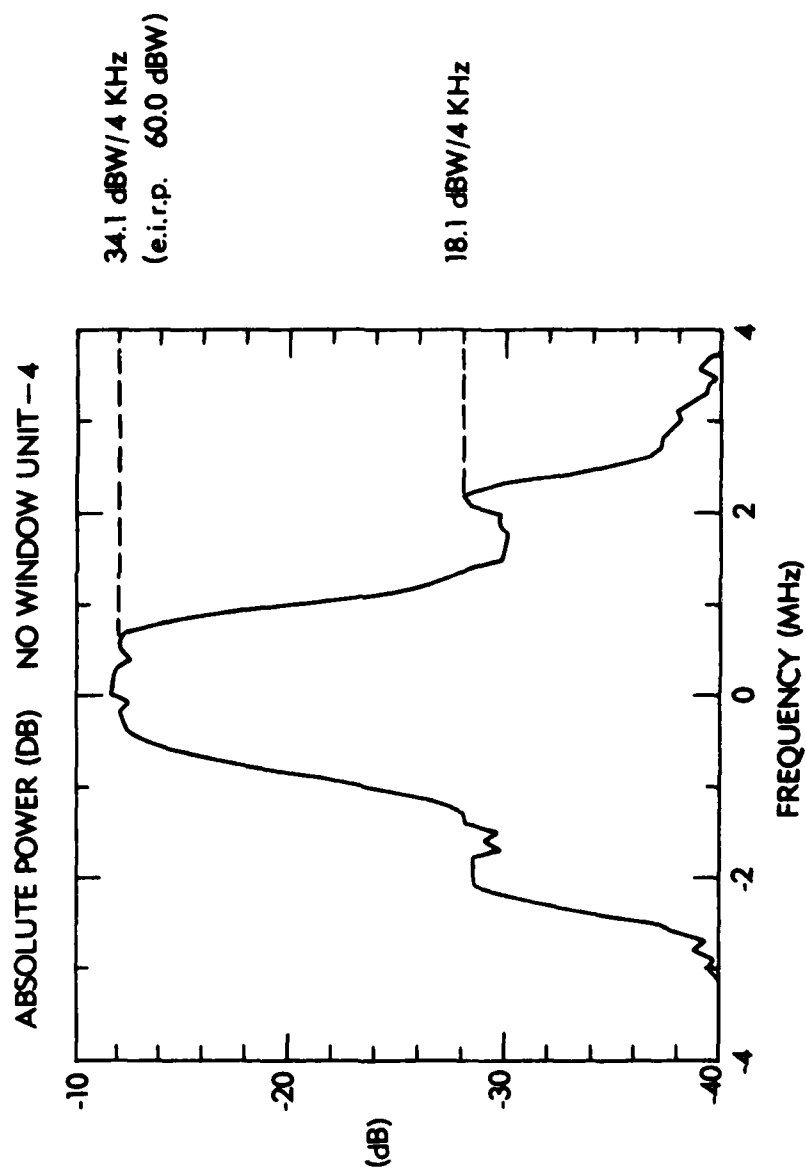
Figure 4-4.   Maximum QPSK Out-of-Band Emission at HPA Output
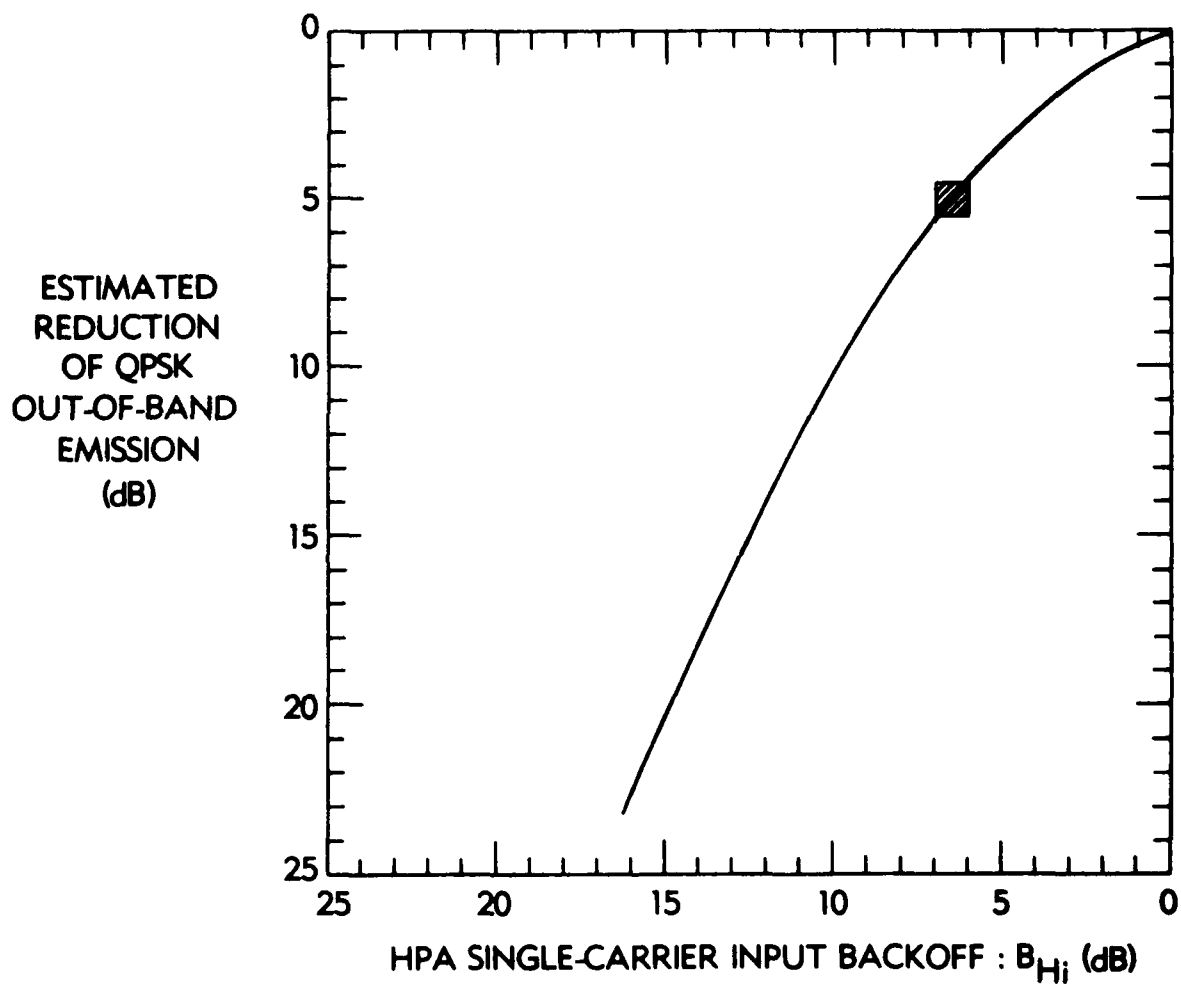(HPA Saturated)

Figure 4-5.   Assumed Relation of Relative Out-of-Band
Emission to HPA Input Backoff

The analysis results in Figure 4-6 give intermodulation distortion (IM) levels falling into the ARPA QPSK carrier. These IM levels are caused by common amplification by the satellite TWTA of the QPSK and FM carriers. This same figure gives estimates of the levels of intermodulation distortion falling into the 660-channel FDM/FM carrier.

Adjacent transponder interference levels caused by IM distortion are shown in Figure 4-6, and all interference levels are summarized in Table 4-4.

Table 4-4 - Interference Levels into ARPA QPSK Carrier

			Remarks
C/I_{IM}.	(Intermodulation Distortion (IM))		No Appreciable IM Expected
C/I_{ATrI}.	(Out-of-Band Emission from Adjacent Trans-ponders)	27.0 dB	Same as previous estimates
C/I_{ext}.	(Adjacent Satellite Interference)	26.0 dB	Same as previous estimates
C/I_{ext}.	(Terrestrial System Interference)	26.0 dB	Same as previous estimates
Total C/I Estimate		21.5 dB	(Previous estimate of 19.0dB)

Note: The slightly higher (better) C/I estimate will not significantly affect previous link margin estimates.

Relative Out-of-band emission (OBE) levels caused on the up-path by the OPSK carrier (due to spectrum spreading caused by the nonlinear HPA characteristics) are summarized in Table 4-5.
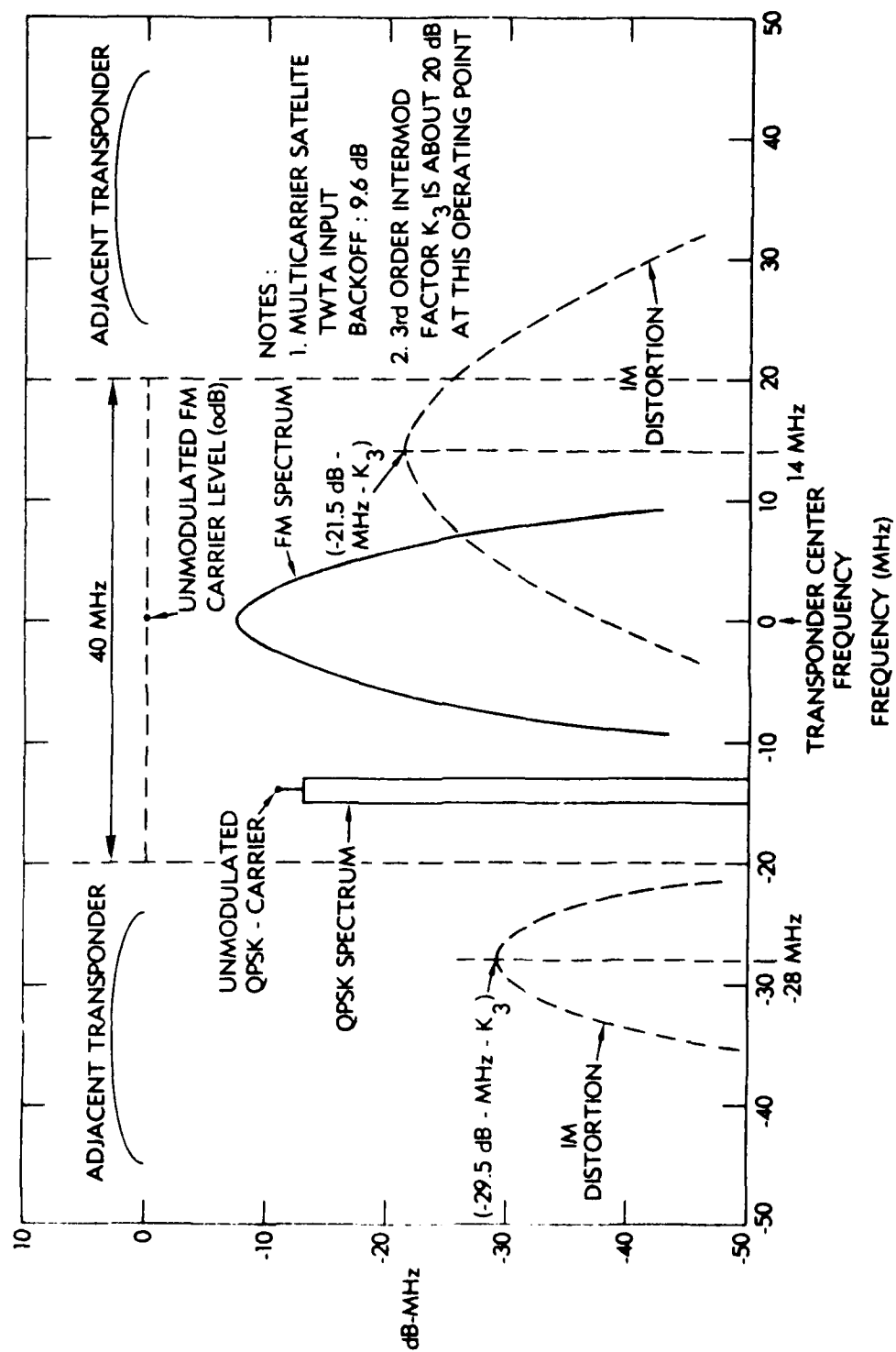
Figure 4-6. Estimated Intermodulation Distortion Spectrum at Satelite
TWTA Output

Table 4-5. Interference Caused by the ARPA Carrier into the
FM Carrier in the Same Transponder and into
Carriers in Adjacent Transponders

		Remarks
Maximum QPSK OBE (dBW/4 kHz)	~8.1	±2 MHz from QPSK carrier center frequency
OBE into FM carrier	negligible	About 19 MHz separation
OBE into adjacent transponder (dBW/4 kHz)	<-2	Near band-edge
IM distortion (C/I) into FM carrier (dB)	50 dB	
IM distortion power density into adjacent transponder (dBW/4 kHz)	-39.5	Near band-edge

Note: These results show that interference effects are expected
to be negligible.

For the original two-carrier frequency plan, the level
of IM distortion falling into the FM carrier and into the adjacent
transponders is concluded to be negligible. The level of out-of-
band emission caused by the QPSK carrier on the up-path to the
satellite is also negligible. The above conclusions should be
reexamined for other frequency plans.

Estimates of overall in-band transmission impairments
experienced by the QPSK carrier over the transmission path are
given in Figure 4-7. This figure shows the increase of carrier-to-
noise ratio required for a bit error rate (BER) of 5×10^{-3} above
theoretical ideal value. This estimate is obtained via a simplified
computer simulation where modem synchronization circuits are assumed
to be hard-wired. The satellite transponder filters and the FDM/FM
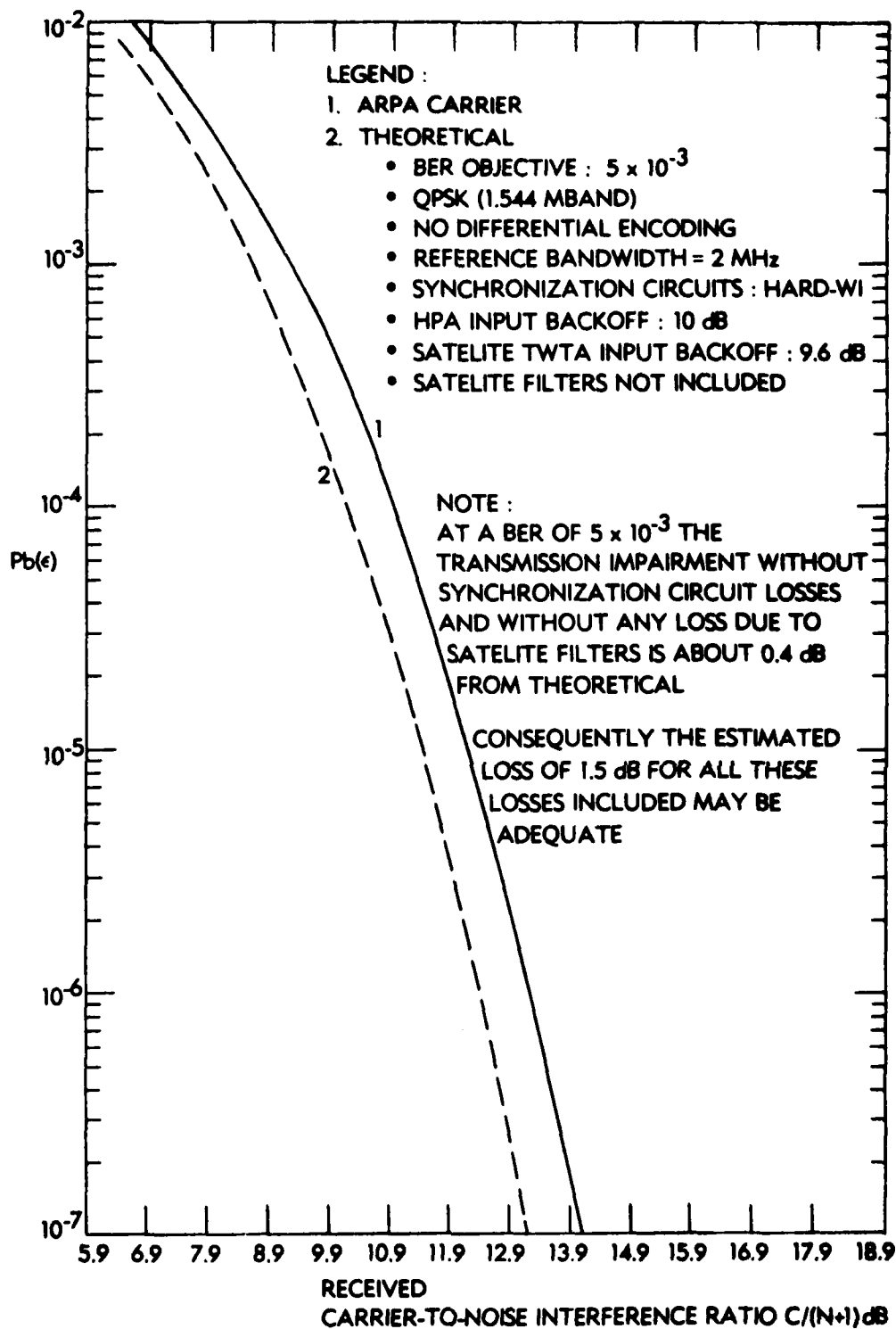carrier were not included in this particular simulation.

Figure 4-7. Bit-Error Rate versus Received C/N Ratio

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The link budgets and margins are summarized in Table 4-6. The link margins obtained are slightly larger (by 0.3 dB) than the estimates in Table 4-3. This difference is caused by the fact that IM distortion levels falling into the QPSK carrier have been found to be negligible for the original two-carrier frequency plan. This accounts for the fact that the total C/I allocation for interference effects is slightly better than previous estimates (C/I of 21.5 dB instead of 19 dB). The IM levels would be different for other frequency plans.

It presently appears that the assumed transmission impairment allowance of 1.5 dB (for modem implementation, etc.) may be adequate. This is based on the estimated transmission impairment of 0.4 dB (Figure 4-7) obtained for the case where synchronization circuits are hard-wired and where the impact of the transponder filters is omitted. When these effects are included the total impairment would probably not exceed 1.5 dB. Any additional loss due to the satellite filters group delay distortion could be determined through the more complete computer simulation. If losses become excessive, the QPSK carrier could be shifted towards the transponder band-center where the group delay distortion is less pronounced. The additional loss due to synchronization circuits should be evaluated in future simulation efforts.

It appears that the transmitted e.i.r.p. should probably be increased to improve the link margins. Since a 75-W HPA will be used, there is sufficient available e.i.r.p. at each earth station to achieve this end. However, the level of off-axis radiation (adjacent satellite interference) must be examined before this can be recommended.

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Table 4-6

Link Characteristics and Margins for ARPA QPSK Carrier

Loop-Back Path Up-Path	Reston	Lexington	Menlo Park	Marina Del-Rey	Remark
HPA Output Backoff (B_{HO}(dB))	5.8	6.4	6.0	5.0	75 Watt-HPA
HPA Input Backoff (B_{Hi}(dB))	10.8	11.5	11.0	9.8	
Up-Path e.i.r.p. (dBw)	60.0	59.4	59.7	60.7	
Ratio of e.i.r.p. to Saturation Level	-21.0	-21.0	-21.0	-21.0	QPSK Carrier
(Multicarrier Satellite TWTA Input Backoff: (B_{Si}(dB))	9.6	9.6	9.6	9.6	(QPSK & FM Carriers)
Rain Margin (dB)	0.5	0.5	0.5	0.5	
Up-Path Thermal C/N (dB)	18.1	18.2	18.2	18.1	Bandwidth=2 MHz
Down-Path Ratio of e.i.r.p. to saturation Level (dB)	-16	-16	-16	-16	QPSK Carrier
Rain Margin (dB)	0.1	0.1	0.1	0.1	
Down-Path Thermal C/N (dB)	10.8	9.6	10.1	9.7	
System Thermal (C/N (dB)	10.1	9.0	9.5	9.1	2 MHz
Estimated Interference Level C/I (dB)	21.5	21.5	21.5	21.5	IM Negligible
System C/((N+I) (dB)	9.8	8.8	9.2	8.8	
Required C/((N+I) (dB)	8.6	8.6	8.6	8.6	2 MHz
Margin (dB)	1.2	0.2	0.6	0.2	slightly better than previous estimates

4.3.3 COMPUTER SIMULATION OF THE "HYBRID TRANSPONDER" FREQUENCY PLAN

Preliminary digital computer simulations have been performed of the 17-carrier "Hybrid" Westar transponder frequency plan utilizing the CHAMP2 computer program. Table 4-7 summarizes the characteristics of each signal.

The FM signals in the transponder are all tone modulated and were simulated as such. All of the 32 kbit/s BPSK signals were simulated as sinusoids at their appropriate center frequencies. The eight QPSK signals were generated individually with the parameter values as shown in Table 4-7.

The EISN (Experimental Integrated Switched Network) signal was generated using the "short-pulse" technique. In this scheme, the modulating pulse driving the modulator prefilter exists for 25 percent of the symbol duration. Since the symbol rate, R_s, is 1.544 MSPS, the symbol duration is 648 ns. One-quarter of a symbol is, therefore, 162 ns. This signal was then passed through an equalized 7-Pole Butterworth filter having a $BT_s = 1.0$. The modulated signal was then passed through the HPA which was operated with an input backoff = -9 dB and an output backoff = -4.7 dB).*

The other QPSK signals in the transponder were generated utilizing the symbol rates shown in Table 4-7. These signals were simulated as conventional QPSK. After generations, each signal was passed through its own Butterworth filter. At this point, all the signals were attenuated individually such that the ratios of the power in each signal relative to the EISN signal were equal to the relative levels shown in Table 4-7. All sampled signals were then interpolated to change sampling rate in order to make the sampling rates for all signals approximately the same (within 2 percent of each other). This condition of equal sample rate must

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*All filter and nonlinear amplifier characteristics used in the simulation came from: Devieux, C., "Preliminary Results for Link Margin Evaluation for the ARPA 1.544 Mband QPSK Carrier," COMSAT IOM to L. Palmer, 6/29/79. This data was summarized in the First Quarterly Progress Report under this contract.

Table 4-7. Description of "Hybrid Transponder" Frequency Plan

Carrier #	Relative Carrier Freq. Location (MHz)	Modulation	Symbol Rate (Mbps MHz) (Noise - BW)	BT_s	Power Relative to the EISN Carrier (dB)	Remarks
1	-3.5	FM	(0.7)	-	-4.6	Ranging
2	-2.5	FM	(0.7)	-	-4.7	Ranging
3	-16.0	BPSK	0.032	-	-24.0	
4	-13.0	BPSK	0.032	-	-24.0	
5	-11.0	BPSK	0.032	-	-14.5	
6	-10.5	BPSK	0.032	-	-14.5	
7	-9.0	BPSK	0.032	-	-14.5	
8	+0.2	BPSK	0.032	-	-14.5	
9	-16.5	QPSK	0.112	2.6	-7.0	FEC, r = 1/2
10	-5.0	QPSK	0.450	2.7	-2.2	FEC, r = 3/4
11	-14.5	QPSK	1.544	1.3	+2.4	FEC, r = 3/4
12	+2.5	QPSK	0.772	1.49	-2.1	FEC, r = 7/8
13	+4.5	QPSK	0.772	1.49	-1.7	FEC, r = 7/8
14	+8.5	QPSK	0.772	1.49	+1.2	FEC, r = 7/8
15	+10.0	QPSK	0.772	1.49	+0.9	FEC, r = 7/8
18	-0.2	FM	0.075	-	-9.0	Ranging
19	+14.5	QPSK	1.544	1.0	0.0	EISN

exist in order to sum all the signals together at the satellite input. Four distinct QPSK symbol rates were used and Table 4-8 gives the signal parameters of interest for the interpolation operation.

Table 4-8. Interpolation Parameters for
Hybrid Transponder Simulations

Symbol Rate	Number of Samples per Symbol	Intermediate Sampling Rate	Interpolation Factor	Final Sampling Rate
1.544	12	18.53	6	111.17
0.772	12	9.264	12	111.17
0.450	22	9.900	11	108.90
0.112	24	2.688	41	110.20

After interpolation and scaling, all signals were com-bined and passed through the filter/TWTA/filter combination that represents the satellite. The TWTA's input backoff was set at -11.79 dB from saturation (output backoff was measured as -7.09 dB). Frequency spectra were obtained at the input and output of the satellite, these are shown in Figures 4-8 and 4-9, respectively. These spectra cover a band of approximately three transponder bandwidths, 110 MHz, in order to show the magnitude of the adjacent transponder interference levels.

After the satellite, the combined signal was deinter-polated by a factor of six (the interpolation factor used for the EISN signal) and then passed through the receive modem filter which was an equalized Butterworth filter with a BT_s - product equal to unity and centered on the EISN signal center frequency. Detection and bit-error-rate (BER) measurements were made on the EISN signal with the results, expressed in the form of dB-loss relative to theoretical as a function of BER, shown in Table 4-9.

**Table 4-9. Loss (dB relative to ideal) as a
Function of BER**

<u>Bit - Error - Rate (BER)</u>

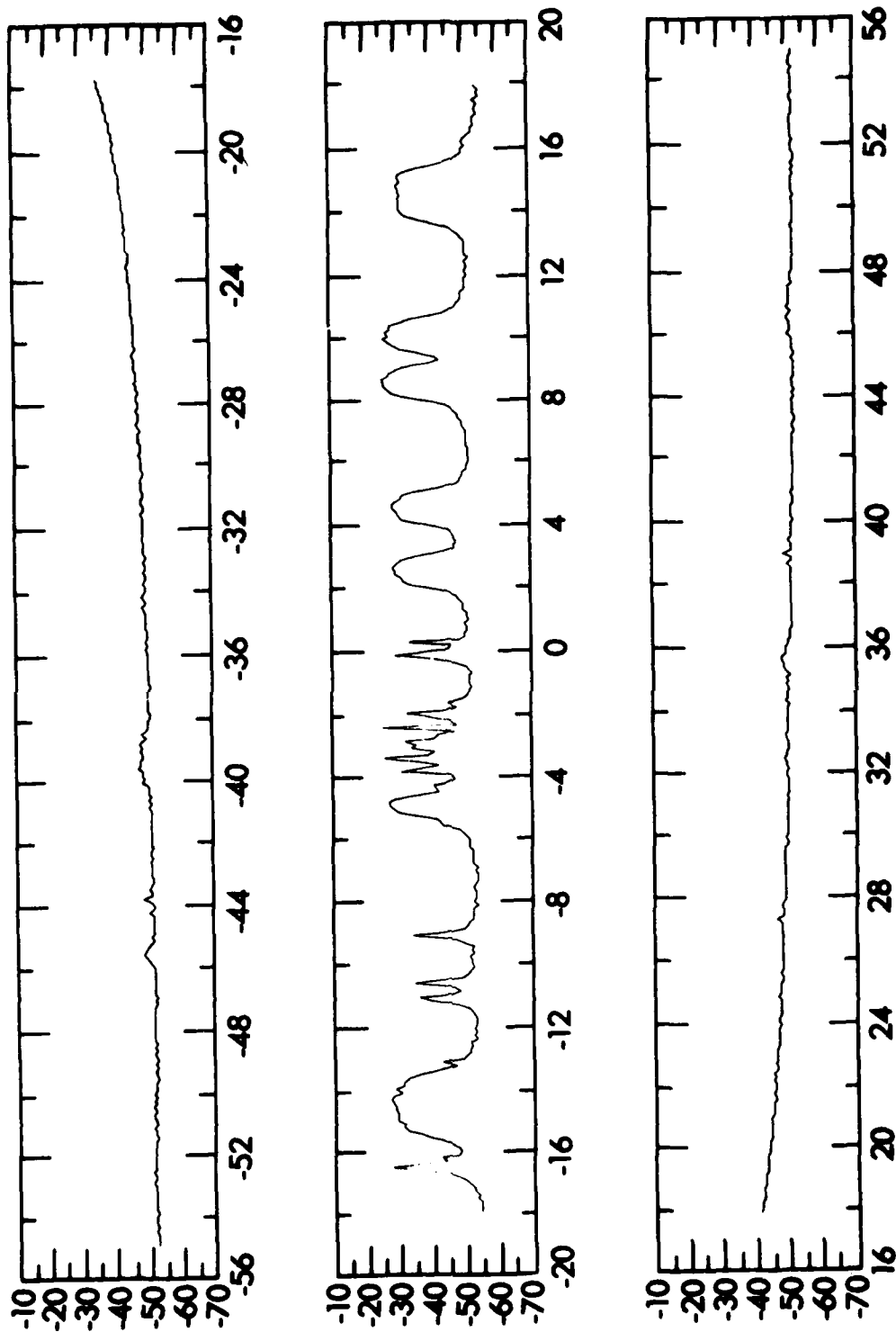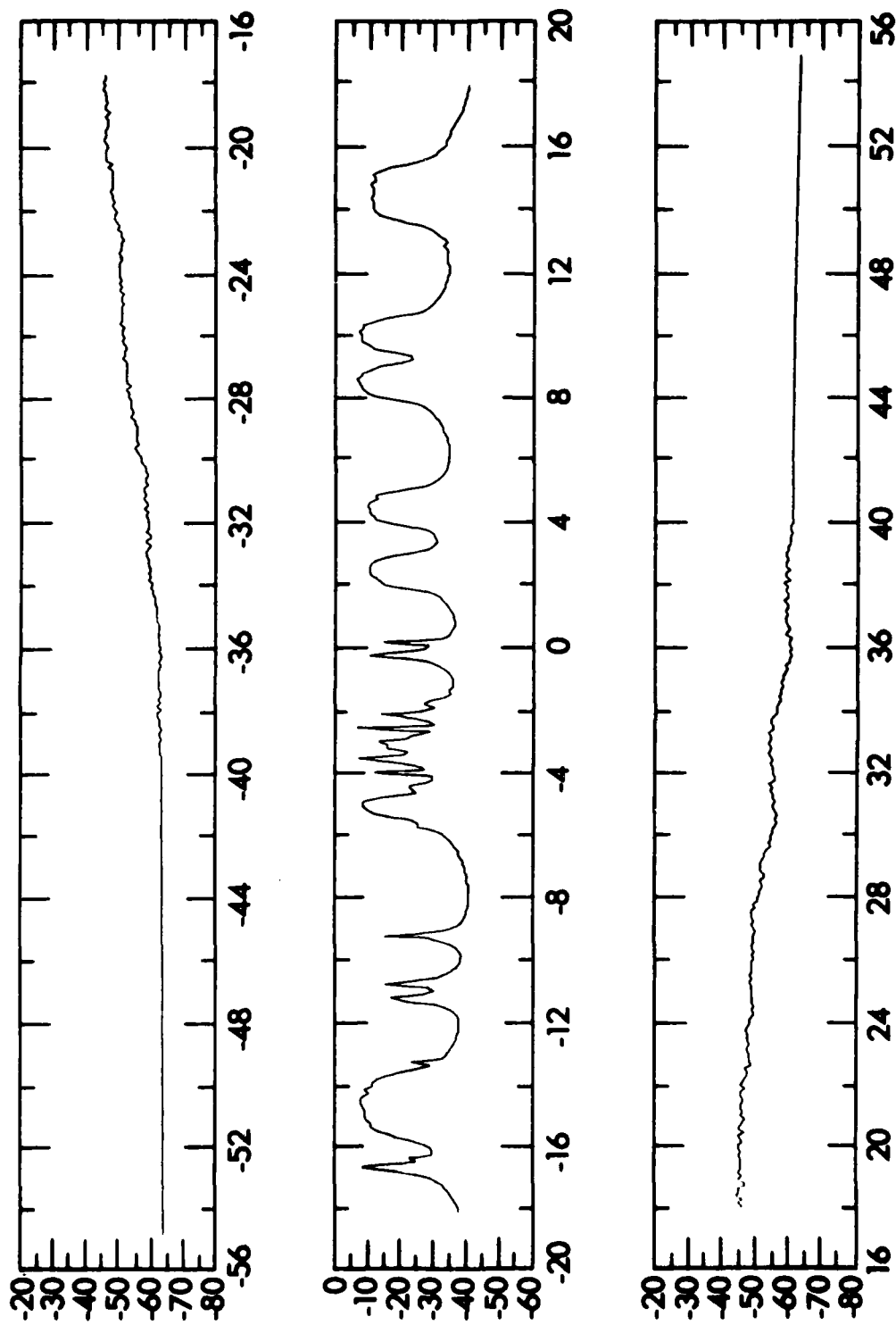|	$\underline{10^{-4}}$	$\underline{10^{-5}}$	$\underline{10^{-6}}$	$\underline{10^{-7}}$	$\underline{10^{-8}}$	$\underline{10^{-9}}$	$\underline{10^{-10}}$
Loss (dB)	0.1	0.24	0.37	0.52	0.7	0.88	0.92

Figure 4-8. Spectral Density at Input to Hybrid Transponder

Figure 4-9. Spectral Density at Output of Hybrid Transponder

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